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YAWSONDE TESTS FOR PROTOTYPES OF THE 155MM INTERMEDIATE VOLATILITY AGENT PROJECTILE

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Twelve yawsonde-instrumented, intermediate volatility agent (IVA) projectiles were tested at the BRL Transonic Range facility during August 1980. Two payload designs were tested. These 155mm prototype binary shell utilize a set of tandem, axially aligned canisters. The canisters are of different internal diameters, however. After rupture of the burst discs that separate the canisters, the interior geometry is not a simple cylinder as in the case of the 155mm M687 or the 8-inch XM736 binary projectiles. This unusual interior geometry cannot be easily analyzed for destabilizing effects of the liquid. Data from Charge 4 and

20. ABSTRACT (Continued):

6 launches indicated stable flights for both canister designs. Previous tests at Dugway Proving Ground (DPG) had shown that one of the designs was unstable at Charge 4, but yawsondes were not employed so little information is available as to the nature of the unstable (or stable) flights. Since a reliable mathematical model is not available to aid in the design of the canister IVA configurations, additional testing must be conducted.

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I. INTRODUCTION

A series of flight tests were conducted to determine the stability of two prototype designs for the 155mm intermediate volatility agent (IVA) binary projectile. Twelve shell with yawsondes were fired at transonic and supersonic launch conditions. All shell were stable. The liquid canister designs for these prototypes were unusual in that the forward and aft canisters were of different internal diameters and this geometry is presently not amenable to stability analyses for the liquid. Designs such as these must be carefully tested.

II. BACKGROUND

Two previously developed binary projectiles, the 155mm M687 and the 8-inch XM736, both employed tandem canisters that were of the same internal diameters. A cut-away view of the XM736 is shown in Figure 1. Upon launch, the burst discs are ruptured and the resulting internal geometry seen by the liquid payload is essentially that of a right circular cylinder. The canister geometries for both the M687 and the XM736 were selected using the concepts of the Stewartson-Wedemeyer theory.[1,2] This theory determines the liquid moments and eigenfrequencies for a wholly or partially filled cylinder. The analysis considers viscous effects and the stability of the liquid/projectile system when the liquid is rotating as a rigid body. Instability will occur if one of the liquid eigenfrequencies is close to the fast precessional mode (nutational frequency) of the projectile. The eigenfrequencies principally depend upon the liquid fill ratio and the cylinder aspect ratio (height/diameter). For the IVA geometry a simple aspect ratio cannot be defined, hence the Stewartson-Wedemeyer theory cannot be directly applied.

Prior to the yawsonde-instrumented flights, laboratory tests were conducted with a liquid-filled gyroscope to examine the use of an average aspect ratio.[3] An average radius ($\overline{a}$) can be determined using the height (2c) and the total volume of the cylinder (V_T),

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[1] K. Stewartson, "On the Stability of a Spinning Top Containing Liquid," J. Fluid Mech., Vol. 5, Part 4, September 1959, pp. 577-592.

[2] E.H. Wedemeyer, "Viscous Corrections to Stewartson's Stability Criterion," BRL Report No. 1325, Aberdeen Proving Ground, Maryland, June 1966. AD 489687.

[3] William P. D'Amico, Jr. and Michael D. Fuller, "Experimental Study of a Liquid-Filled Cylinder with Unequal Internal Diameters," BRL Memorandum Report in publication.

$$\bar{a} = (V_T/2c\pi)^{1/2}$$

The average aspect ratio was then defined as $c/\bar{a}$, and it was used to implement the Stewartson-Wedemeyer theory. Theoretical predictions were then compared to the gyroscope data, and it was determined that the average aspect ratio theory and the data were not consistent. The use of the average aspect ratio concept would produce uncertainty within a projectile design.

Liquid-induced instabilities of the Stewartson-Wedemeyer type are common during spin-up, but only a model for prediction of the liquid eigenfrequencies exists. No estimation of the destabilizing liquid moment during spin-up is available. Spin-up eigenfrequency histories were computed in Reference (3), but the differences between the two designs were quite small and no qualitative arguments could be made as to why one design should be stable while the other should be unstable.

III. HARDWARE DESCRIPTION

A cut-away view of the M687 projectile is shown in Figure 2. The projectile metal parts for the 155mm IVA shell will be those of an M687, but a new set of canisters will be employed. Table 1 lists the physical dimensions of the standard M687 and the two IVA prototypes.

Table 1. Physical Characteristics of 155mm Binary Shell*

Projectile Type	Mass (kg)	Moments of Inertia Ix ($kg \cdot m^2$)	Iy ($kg \cdot m^2$)	Top Canister L (cm)	D(cm)	Rear Canister L(cm)	D(cm)	$c/\bar{a}$
M687	41.95	0.1617	1.767	19.30	10.74	28.57	10.74	4.457
Model A	45.12	0.1733	1.691	15.85	10.80	34.46	11.11	4.469
Model B	46.17	0.1728	1.841	16.84	10.80	32.95	11.43	4.438

*Measurements taken with filled canisters.

For yaw induced launches at Charge 4, Model A was unstable when tested at DPG. Yawsondes were not employed, hence the details of these flights are not available. It is highly possible that poor flight performance for Model A occurred prior to liquid spin-up. Upon launch, the liquid is not rotating. During the down range flight, however, the liquid is spun-up by the projectile. This transfer of angular momentum can be seen in yawsonde determined spin histories as a rapid decrease in the projectile rotation rate at shot exit. Normally this rapid despin is observed for about one second, but theoretical predictions of liquid spin-up and the associated projectile spin-decay indicate that the spin-up process can encompass a large portion of the total time of flight (for a Charge 4-30 second time of flight, an M687 can take 15 seconds to achieve 90 percent of the angular momentum of an equivalent frozen liquid payload).[4]

Table 2 gives a round-by-round history of the test program. A three digit number which was stamped on the projectile was augmented with an A or a B to denote model type. An M109A1 vehicle was used to launch the projectiles. A standard muzzle break was used for Charge 6 launches, while a modified muzzle break (12.7 cm side plates) was used to induce yaw at Charge 4. A muzzle chronograph was used to measure launch velocities (velocities shown in the table have not been corrected back to the muzzle). Time-zero measurements were made using a strain gage attached to the tube.

Table 2. Round-By-Round Summary

CSL Number[a]	BRL Number	Firing Date	Muzzle Velocity (m/s)	FMA[b] (degrees)	Quadrant Elevation (degrees)	Launch Condition[c]
195B	1626	27 Aug 80	336.2	9.5	30	Chg 4/YI
187A	1627	27 Aug 80	349.0	9.5	30	Chg 4/YI
194B	1720	27 Aug 80	338.3	9.5	30	Chg 4/YI
186A	1721	27 Aug 80	337.4	8.5	30	Chg 4/YI
193B	1718	28 Aug 80	334.4	12.5	30	Chg 4/YI
185A	1713	28 Aug 80	339.5	12	30	Chg 4/YI
192B	1714	28 Aug 80	336.8	11.5	30	Chg 4/YI
184A	1715	28 Aug 80	340.5	8	30	Chg 4/YI
189B	1624	28 Aug 80	458.4	----	67	Chg 6
181A	1625	28 Aug 80	462.1	----	67	Chg 6
191B	1716	28 Aug 80	460.9	3	17	Chg 6
183A	1697	28 Aug 80	463.3	----	17	Chg 6

[a]A-type shell contained canisters with a 0.793 cm (5/16 inch) wall thickness, while B-type shell had 0.635 cm (1/4 inch) wall canisters.

[b]FMA is defined as the first maximum angle of yaw and is determined as half of the first peak-to-peak excursion in Sigma N. FMA is taken only as a measure of the first maximum yaw level.

[c]Yaw induction (YI) with a modified muzzle brake with full (12.7 cm) side plates.

[4]C.W. Kitchens, Jr. and N. Gerber, "Prediction of Spin-Decay of Liquid-Filled Projectiles," Ballistic Research Laboratories Report No. 1996, July 1977. AD A043275.

Yawsondes configured in the shape of a standard artillery fuze were installed on the test projectiles.[5] Yawsonde data provide a planar view of the angular motion of the projectile during flight. The angular motion is shown in terms of Sigma N which is the complement of an angle between a vector to the sun and the roll axis of the projectile. Sigma N will vary along the trajectory, but peak-to-peak excursions in Sigma N provide the amplitude of the yawing motion about the trajectory. The spin of the projectile is presented in terms of Phi Dot (Raw), which is the derivative with respect to time of the Eulerian roll angle Phi. For large angular motions, the Phi Dot (Raw) history will exhibit oscillations. The mean of these oscillations should be considered to be the spin.[6] Spin will normally be used in place of the terminology Phi Dot (Raw) in this report.

IV. YAWSONDE DATA

Four rounds fired on 27 August 1980 were launched at Charge 4 with yaw induction. Round 195B was launched with an FMA of 9.5 degrees and was stable (Figures 3 and 4). The fast mode precession damped to less than 2 degrees of peak-to-peak motion by 10 seconds. The spin history shown in Figure 5 was normal. The oscillations on the spin history during the first 5 seconds are produced by the large angular motion that was induced at launch. The effects of the large angular motion on the spin history during the first several seconds cloud the rapid despin of the projectile during the liquid spin-up stage. The second test projectile, Round 187A, had an FMA level similar to the first round. The motion was stable and the fast mode precession was again damped by 10 seconds (Figures 6 and 7). Spin data are shown in Figure 8. The next shell (Round 194B) exhibited behavior similar to the first rounds (Figures 9, 10, and 11). The Sigma N data at 0.75 seconds were apparently clipped. However, the data during the next cycle of the motion were normal. Figures 12 and 13 give the angular motion for Round 186A. An FMA of only 8.5 degrees was observed. The spin history is shown in Figure 14 and was normal.

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[5] W.H. Mermagen and W.H. Clay, "The Design of a Second Generation Yawsonde," Ballistic Research Laboratories Memorandum Report No. 2368, April 1974. AD 780064.

[6] C.H. Murphy, "Effect of Large High-Frequency Angular Motion of a Shell on the Analysis of Its Yawsonde Records," Ballistic Research Laboratory Memorandum Report No. 2581, February 1976. AD B009421L.

A second series of test rounds were launched at Charge 4 with yaw induction on 28 August 1980. The same gun and yaw inducer were used as on the previous day, but slightly higher yaw levels were achieved. The angular motion for Round 193B is on Figures 15 and 16 (FMA of 12.5 degrees). The spin history for this shell (Figure 17) clearly shows a rapid despin of the projectile during the first second of flight as the liquid is being spun-up. Data for the next projectile (Round 185A) are shown in Figures 18, 19, and 20. An FMA level similar to Round 193B was achieved. Figures 21, 22, and 23 give the angular motion and spin histories for Round 192B. An FMA of 11.5 degrees was produced, which was slightly smaller than the two previous rounds. This round was stable with no abnormal behavior. The last round fired at Charge 4 was Round 184A. Data for this round are shown in Figures 24, 25, and 26. This shell had the smallest FMA of any of the rounds within this group, 8 degrees.

On 28 August 1980, shell were also launched at Charge 6. The first two rounds were launched at a quadrant elevation of 67 degrees. The yawsondes were out of view of the sun during the early portions of the trajectories due to the high quadrant elevation, but good data were obtained over the remainder of the flight paths. Data for Round 189B are shown in Figures 27 and 28, while data for Round 181A are shown in Figures 29 and 30. No unusual motions were observed. The final two rounds were launched at a quadrant elevation of 17 degrees, and both shell were stable. The first projectile (Round 191B) had an FMA of 3 degrees. The launch disturbances decayed within 3 seconds and almost no angular motion was evident until the limit cycle behavior returned at 10 seconds (Figure 31). Figure 32 clearly shows the rapid despin of the projectile during the first second of flight. The spin decay during the rest of the flight was dominated by air friction over the projectile. Little data were obtained from the last round of the test program (Round 183A) since the yawsonde was not in view of the sun for the entire trajectory. Available data are shown in Figures 33 and 34, and no unusual behavior was observed.

V. DISCUSSION AND CONCLUSIONS

The yawsonde data gave no indication that either the A or B designs would be unstable. This was not expected, since previous testing at DPG had shown the A configuration to be unstable. Past experiences at DPG with 155mm liquid-filled shell have shown yaw levels similar to those achieved during this test. An important difference is the high altitude at DPG, which would reduce aerodynamic damping due to the low atmospheric density conditions. The tests at the Transonic Range facility were of course essentially at sea level and high humidity/high density conditions. If the stable or unstable flight performance of the A model is attributed to differences in atmospheric density, then the projectile must be considered to be marginally stable. As to conclusions on the stability of the B model, very few can be made.

No unstable flights were observed during the present test sequence, but it would be recommended that yawsonde-instrumented flights be performed at DPG where the companion design was unstable.

The geometry of the proposed IVA payload canisters are not amenable to analysis by available liquid-filled shell theory. Uninstrumented flight tests at DPG demonstrated unstable flight behavior for a canister design with an average aspect ratio of 4.469, while stable flights occurred for a design with an average aspect ratio of 4.438. If the stability of a projectile is modified due to a change in aspect ratio of less than one percent, then the system is a very sensitive one. Without the aid of a rational mathematical model, such a sensitive shell design should be carefully and completely tested.

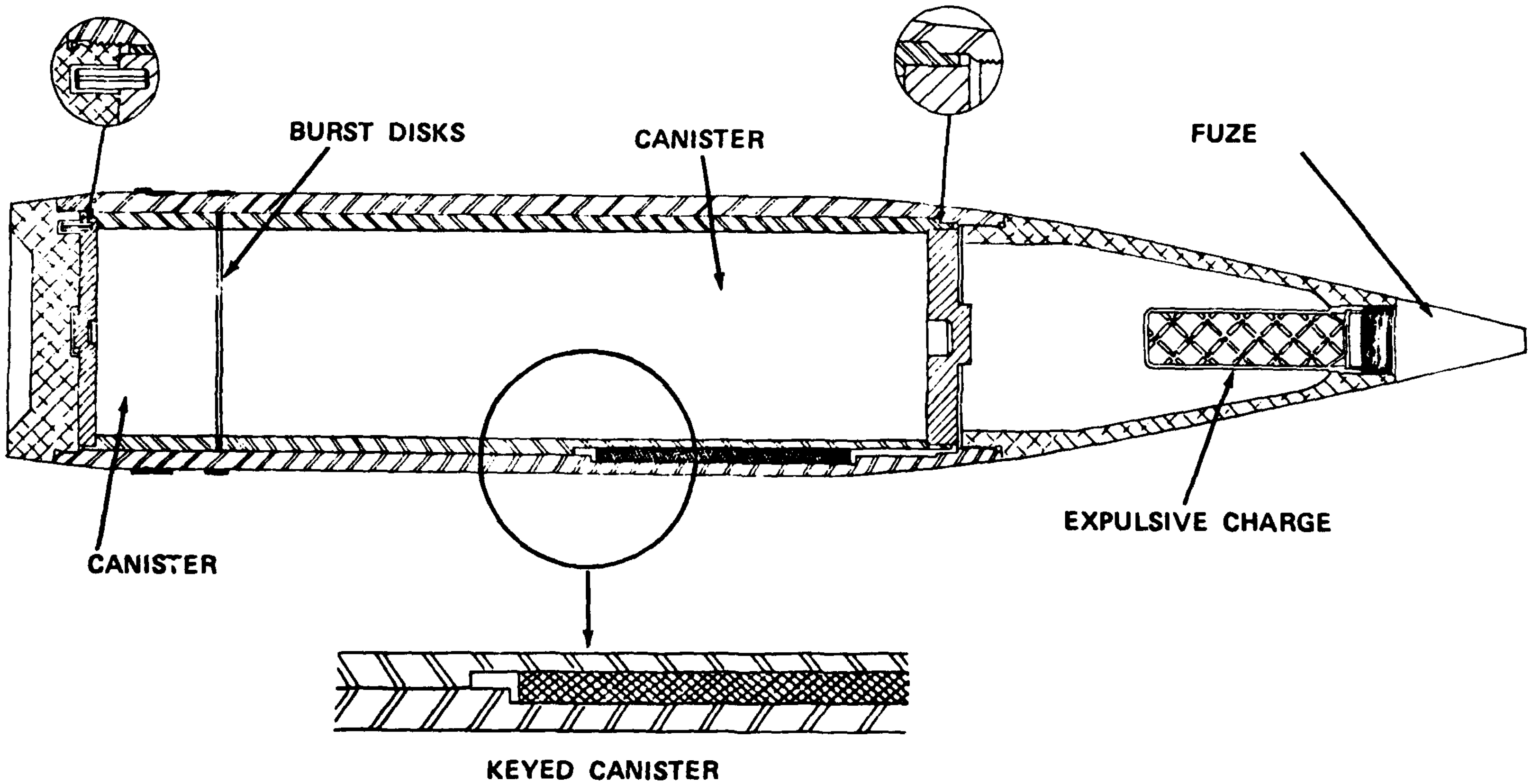

Figure 1. Cut-away view of a standard XM736 projectile, DT II hardware.

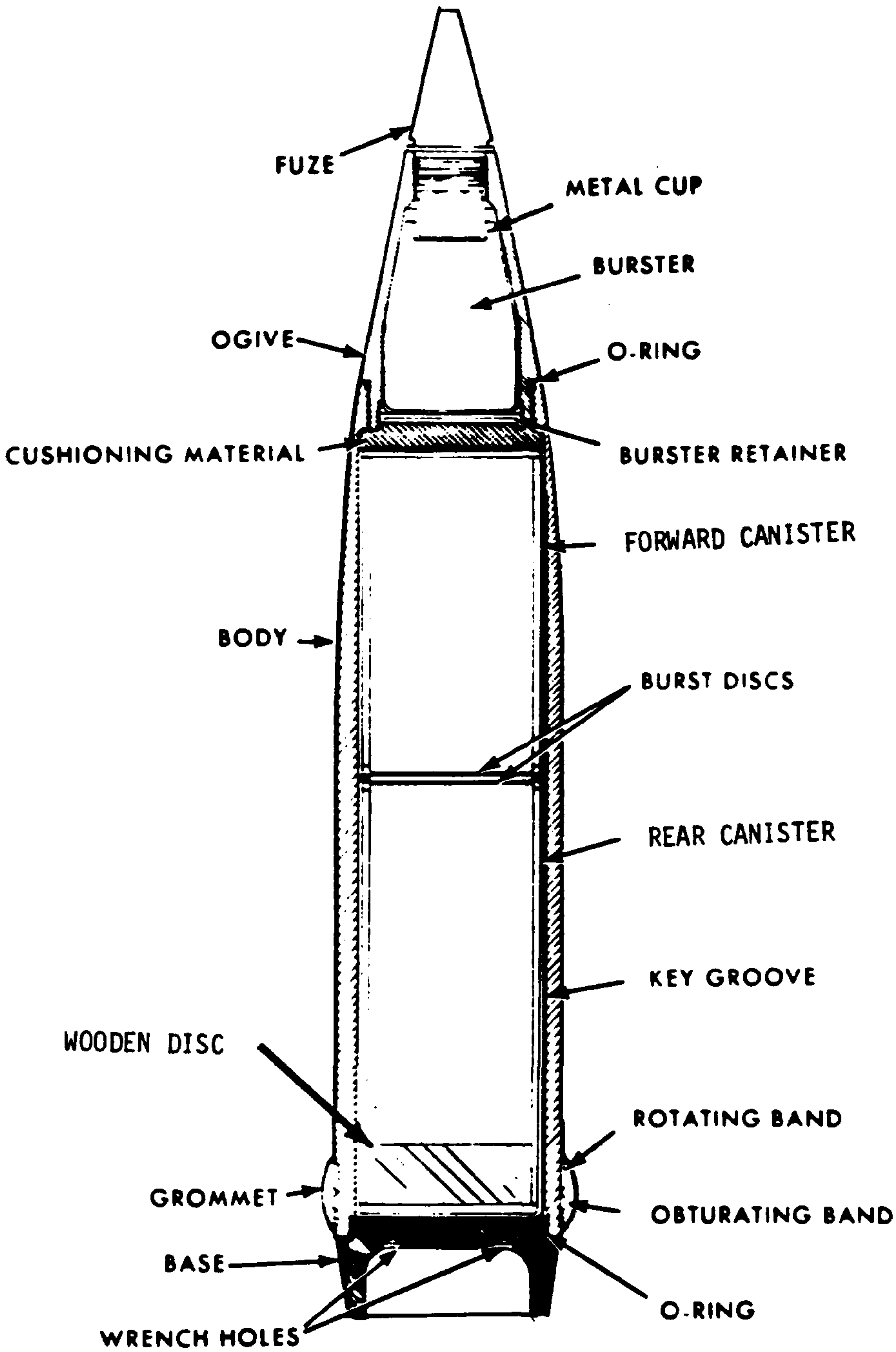

Figure 2. Cut-away view of the 155mm M687 binary projectile.

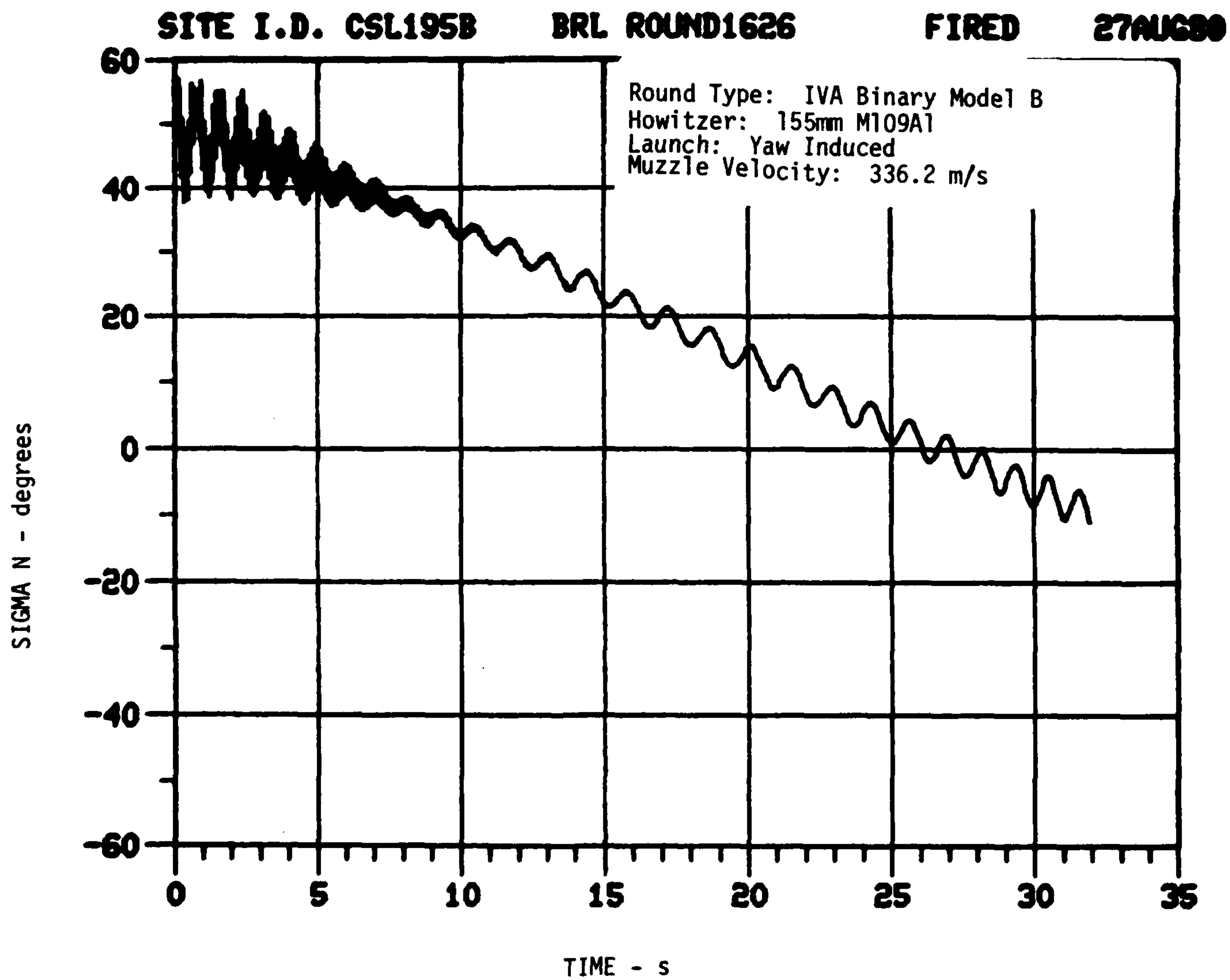

Figure 3. Sigma N versus Time (0-35 s) for Round 195B.

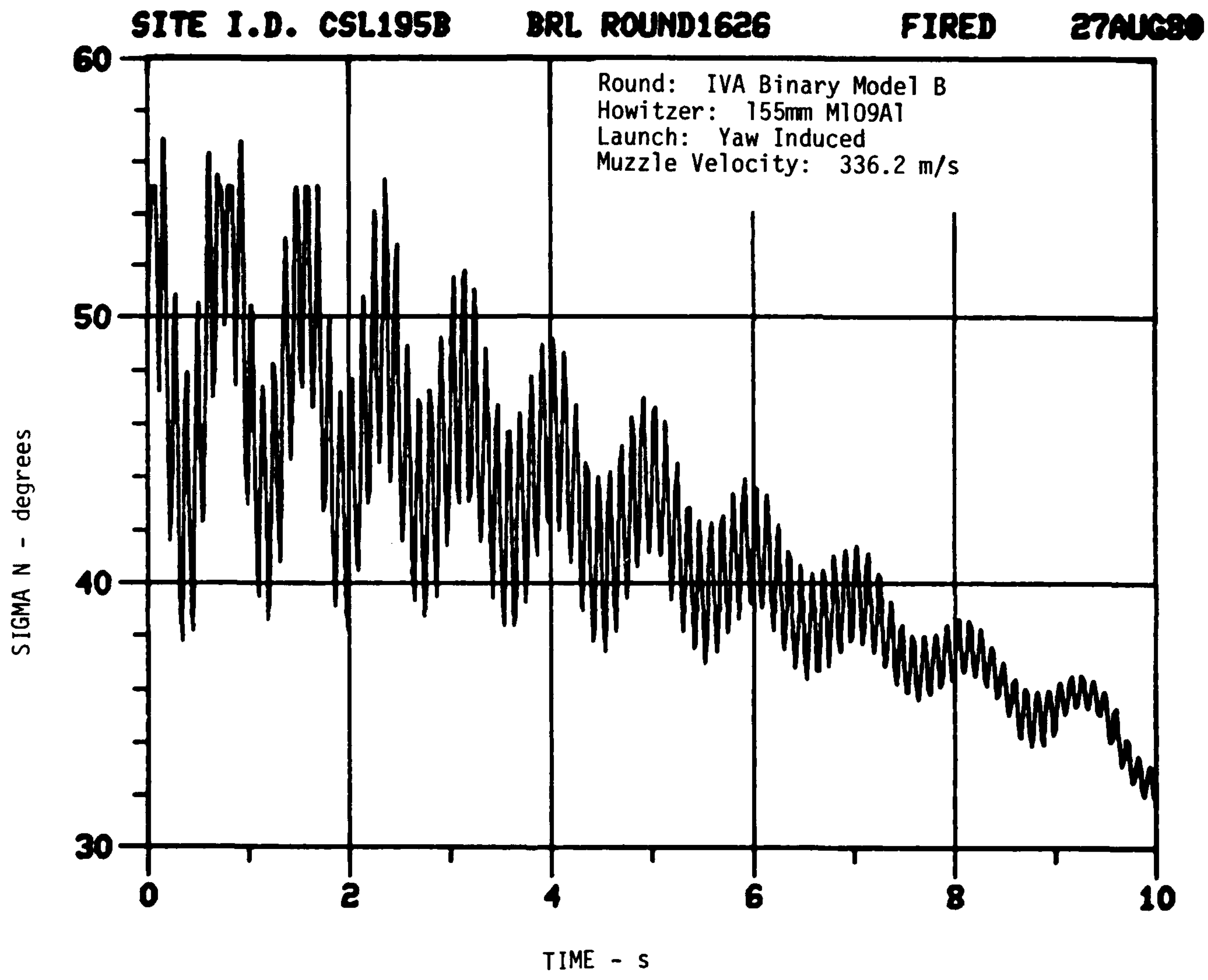

Figure 4. Sigma N versus Time (0-10 s) for Round 195B.

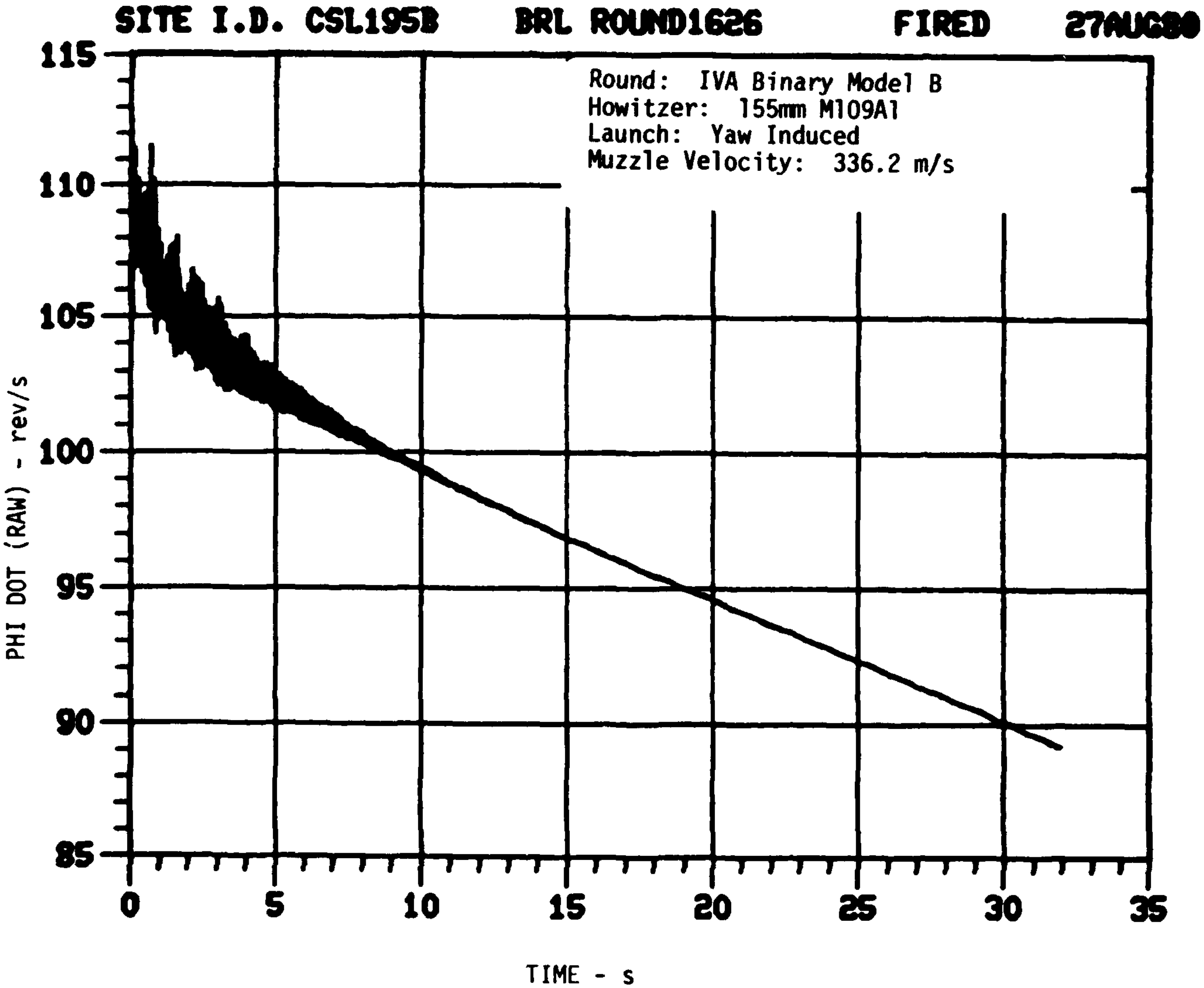

Figure 5. Phi Dot (Raw) versus Time (0-35 s) for Round 195B.

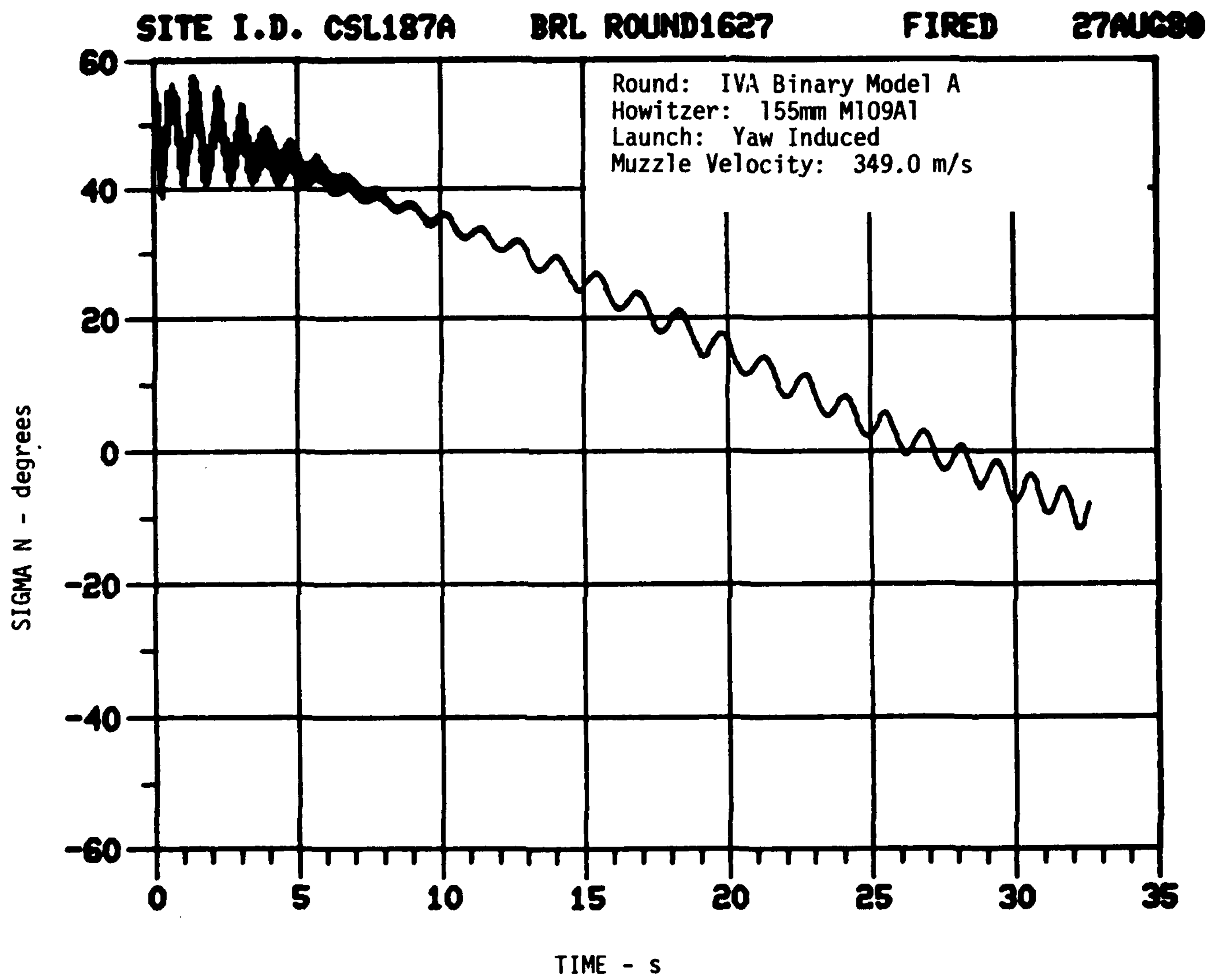

Figure 6. Sigma N versus Time (0-35 s) for Round 187A.

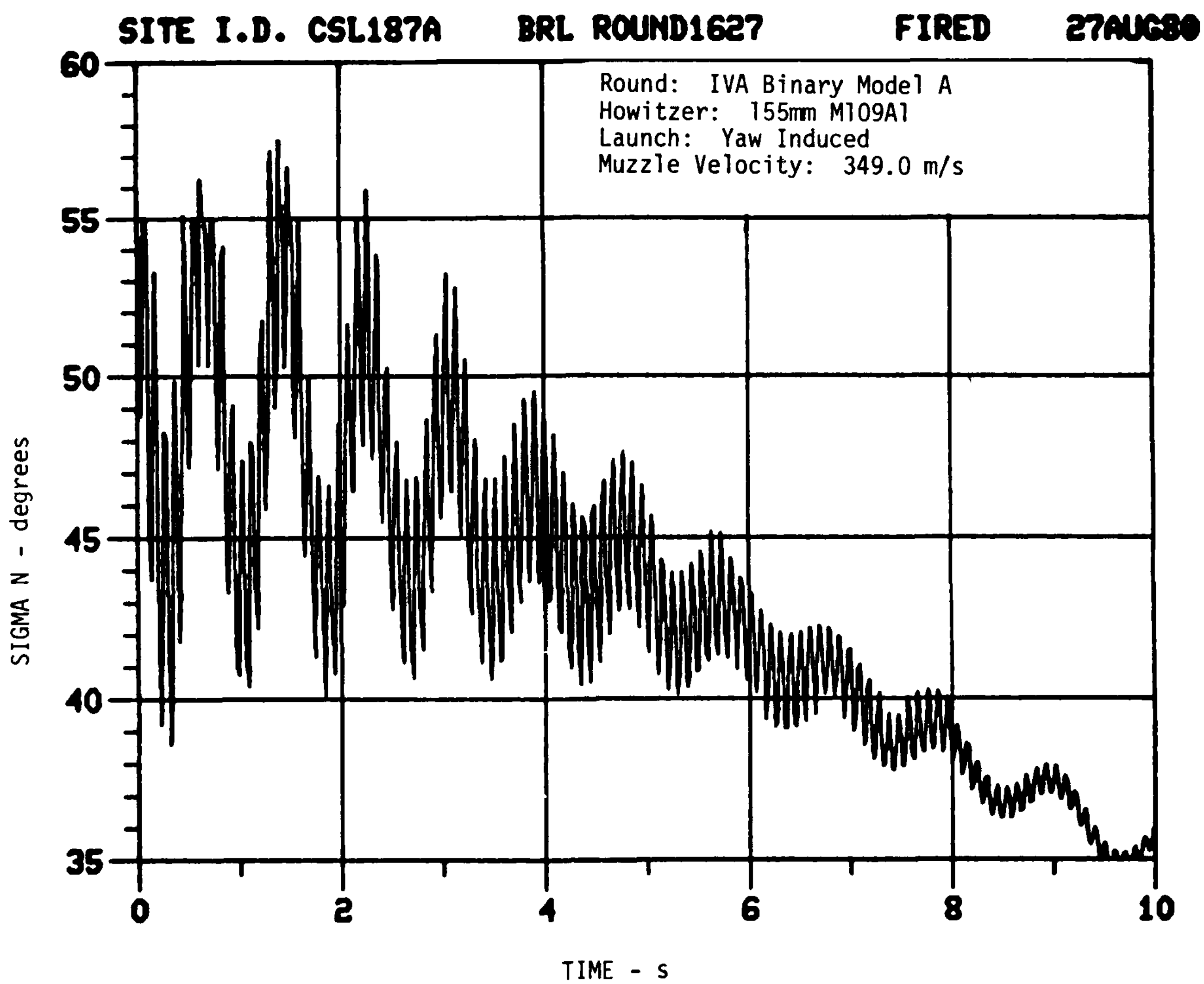

Figure 7. Sigma N versus Time (0-10 s) for Round 187A.

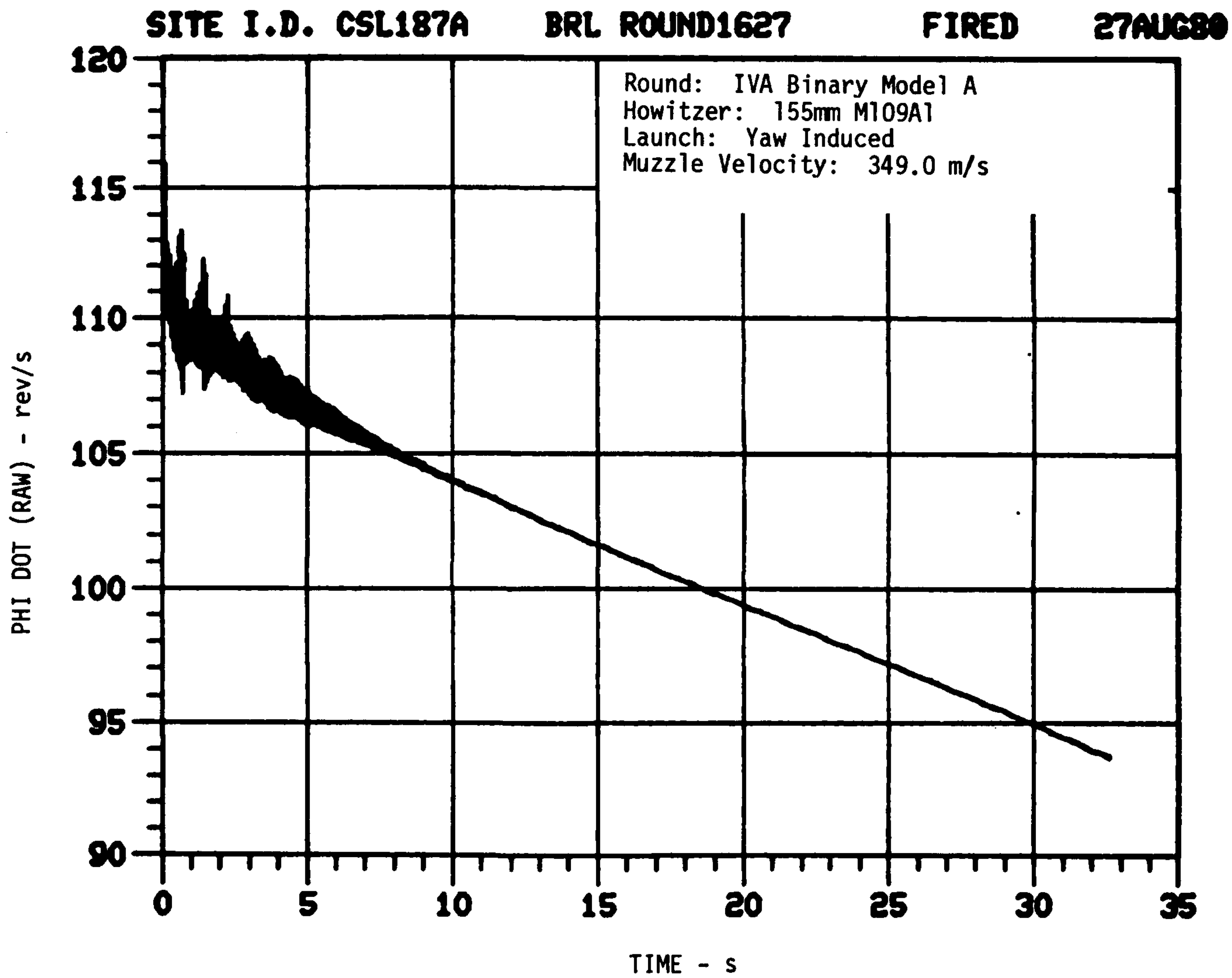

Figure 8. Phi Dot (Raw) versus Time (0-35 s) for Round 187A.

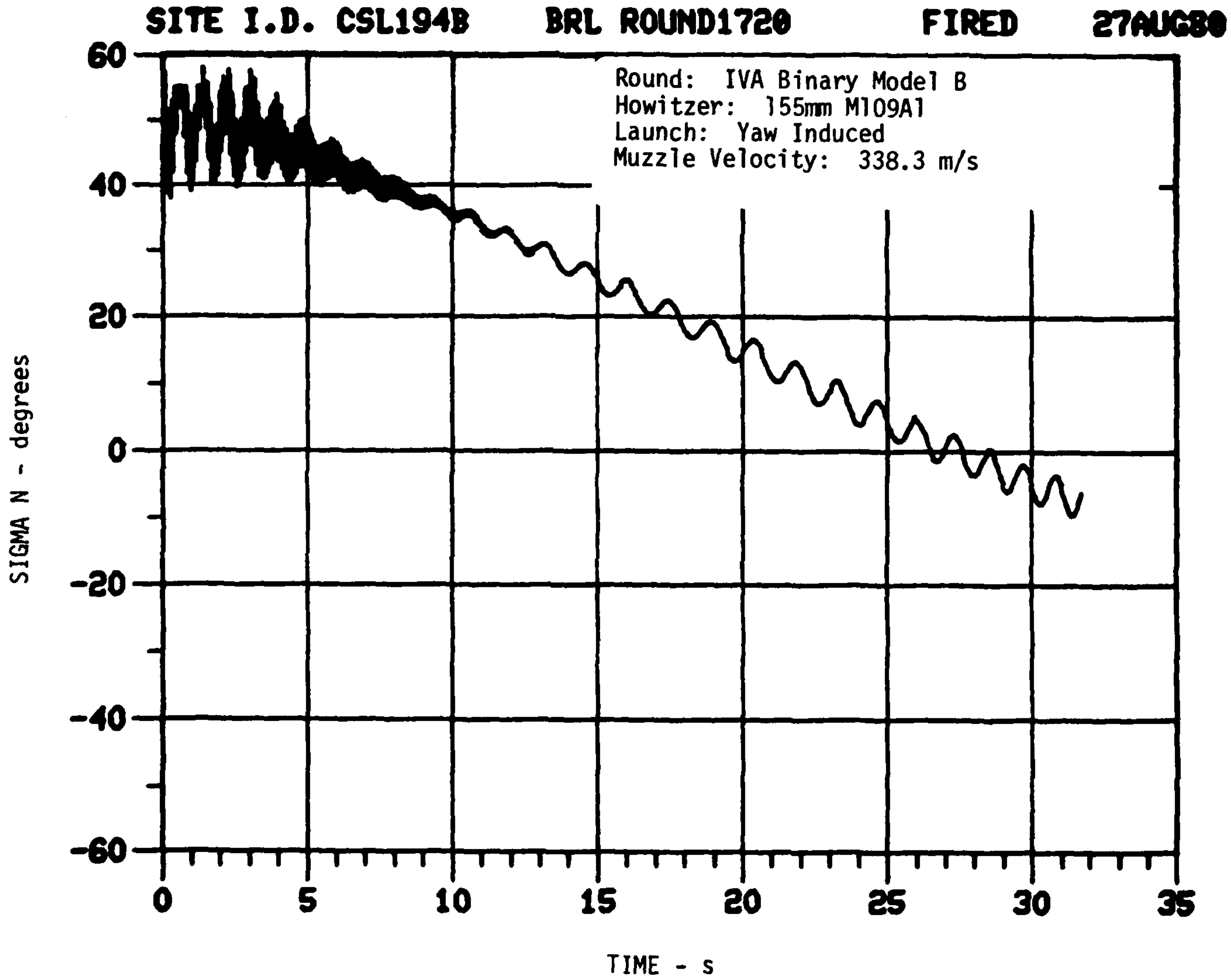

Figure 9. Sigma N versus Time (0-35 s) for Round 194B.

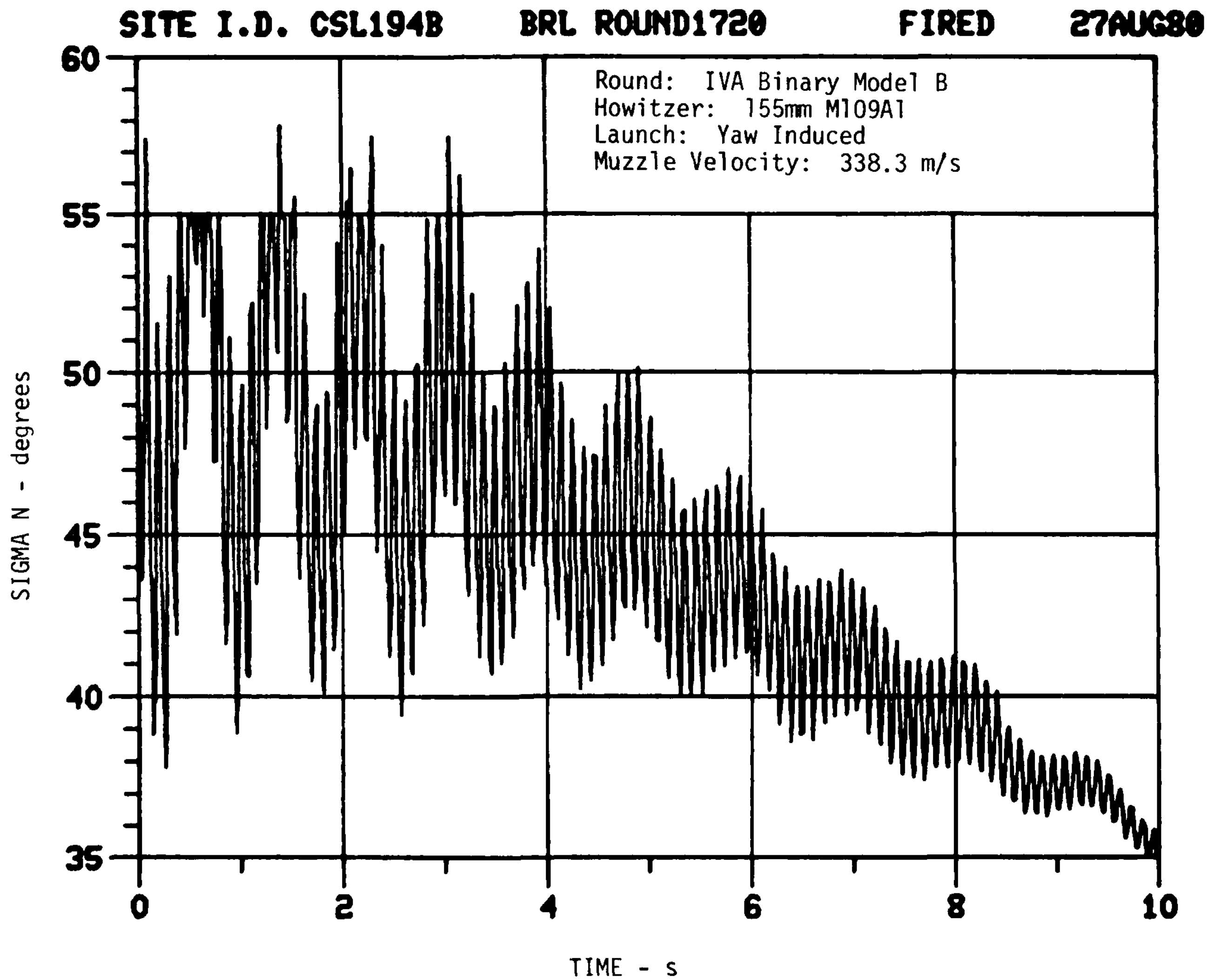

Figure 10. Sigma N versus Time (0-10 s) for Round 194B.

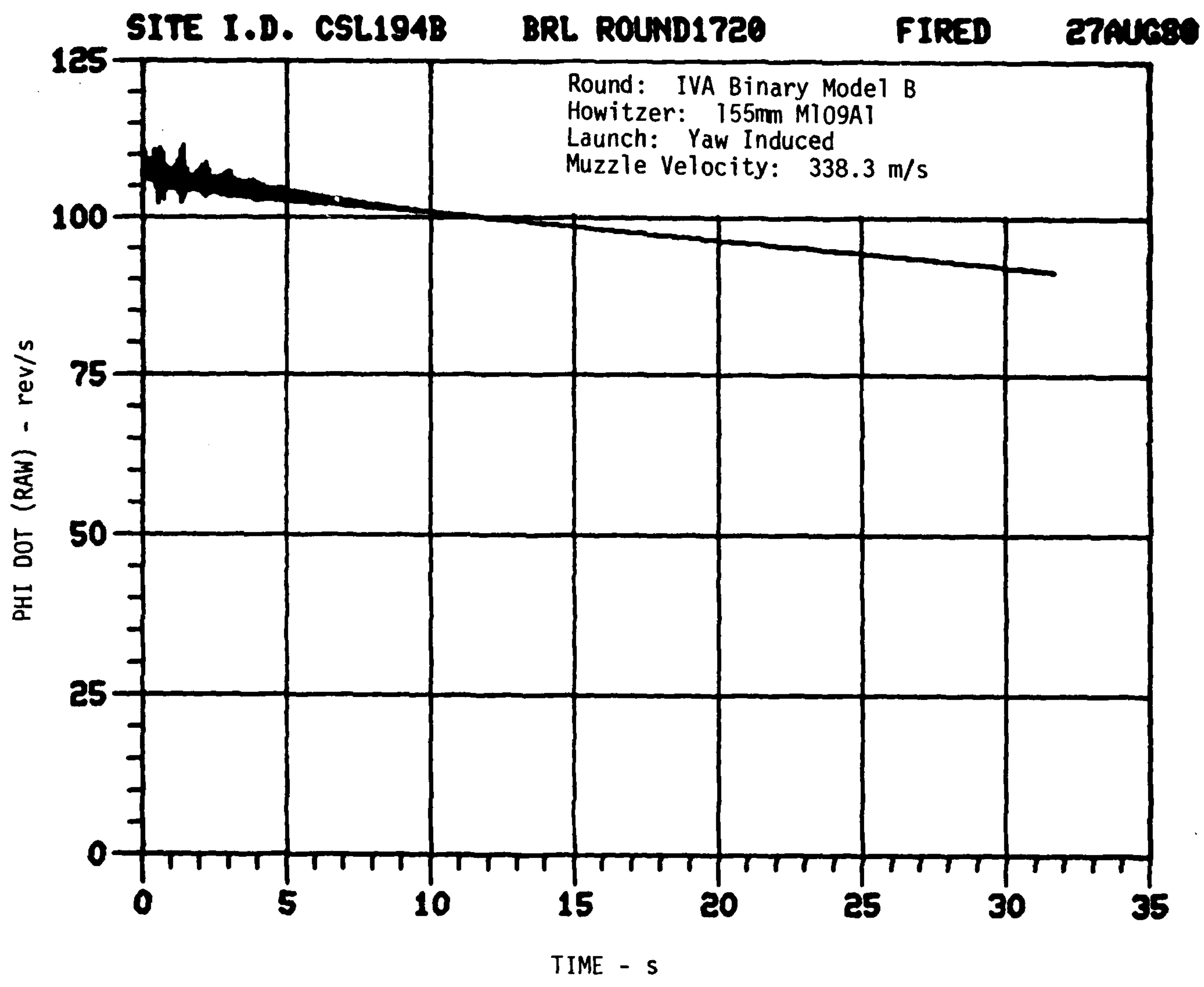

Figure 11. Phi Dot (Raw) versus Time (0-35 s) for Round 194B.

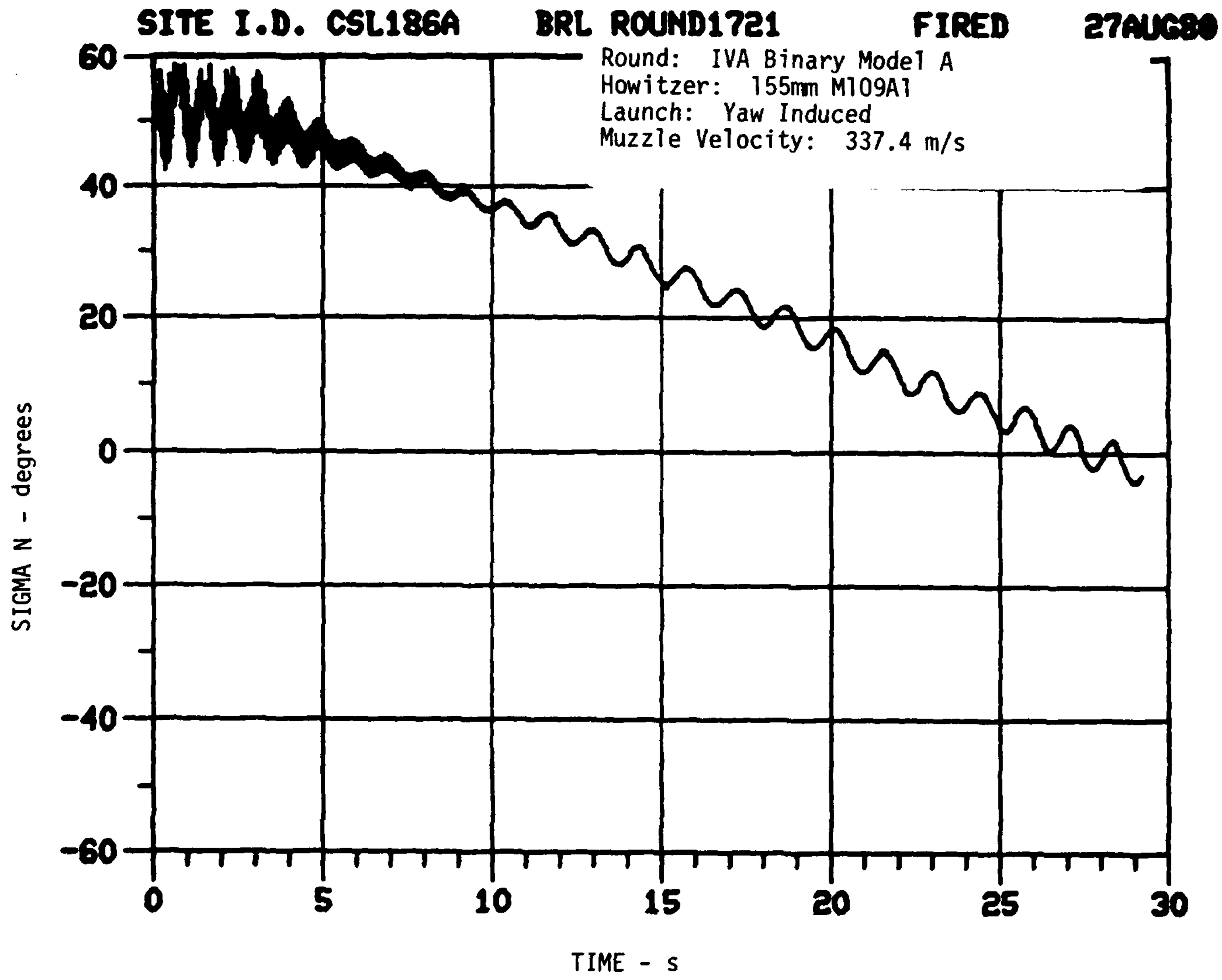

Figure 12. Sigma N versus Time (0-30 s) for Round 186A.

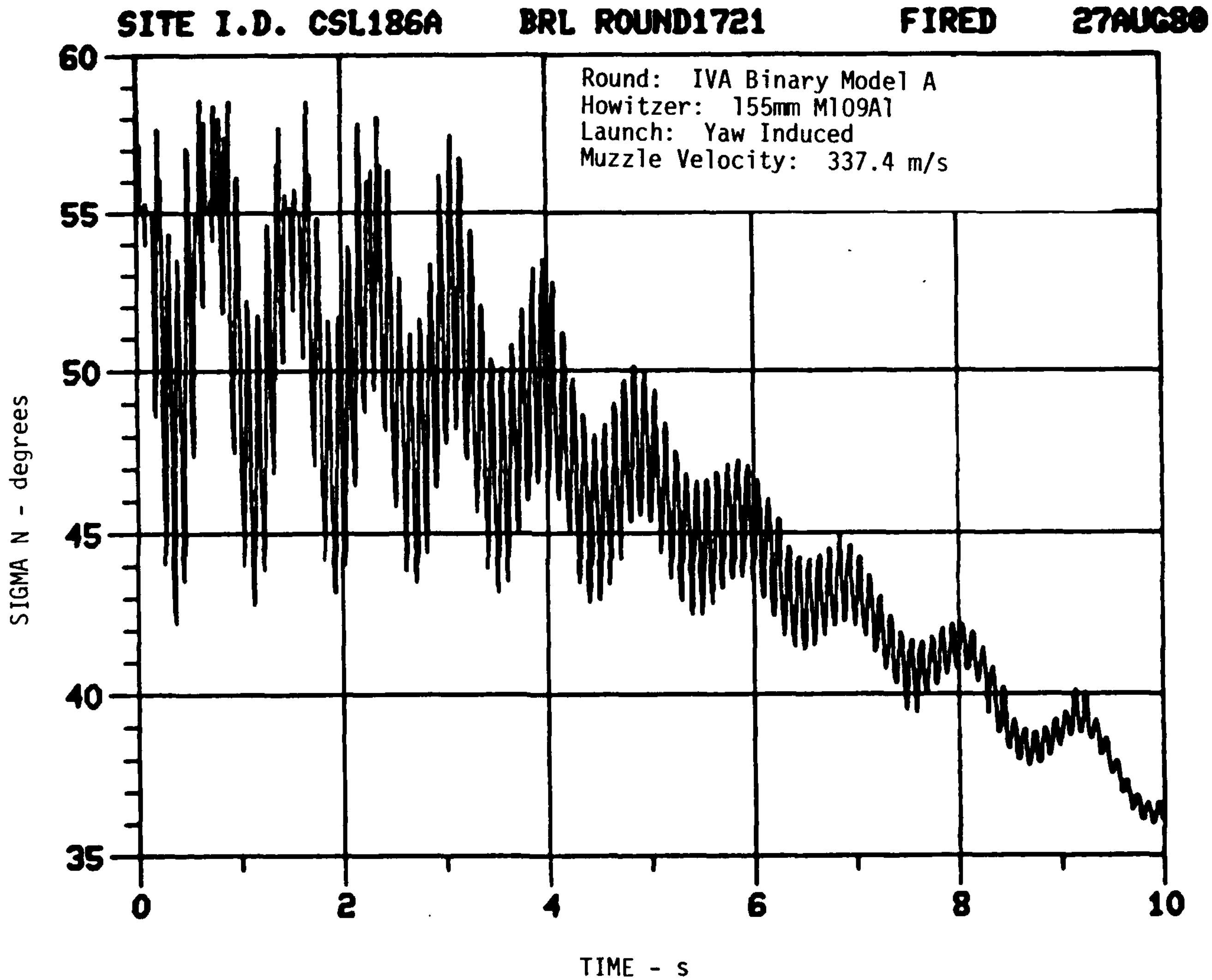

Figure 13. Sigma N versus Time (0-10 s) for Round 186A.

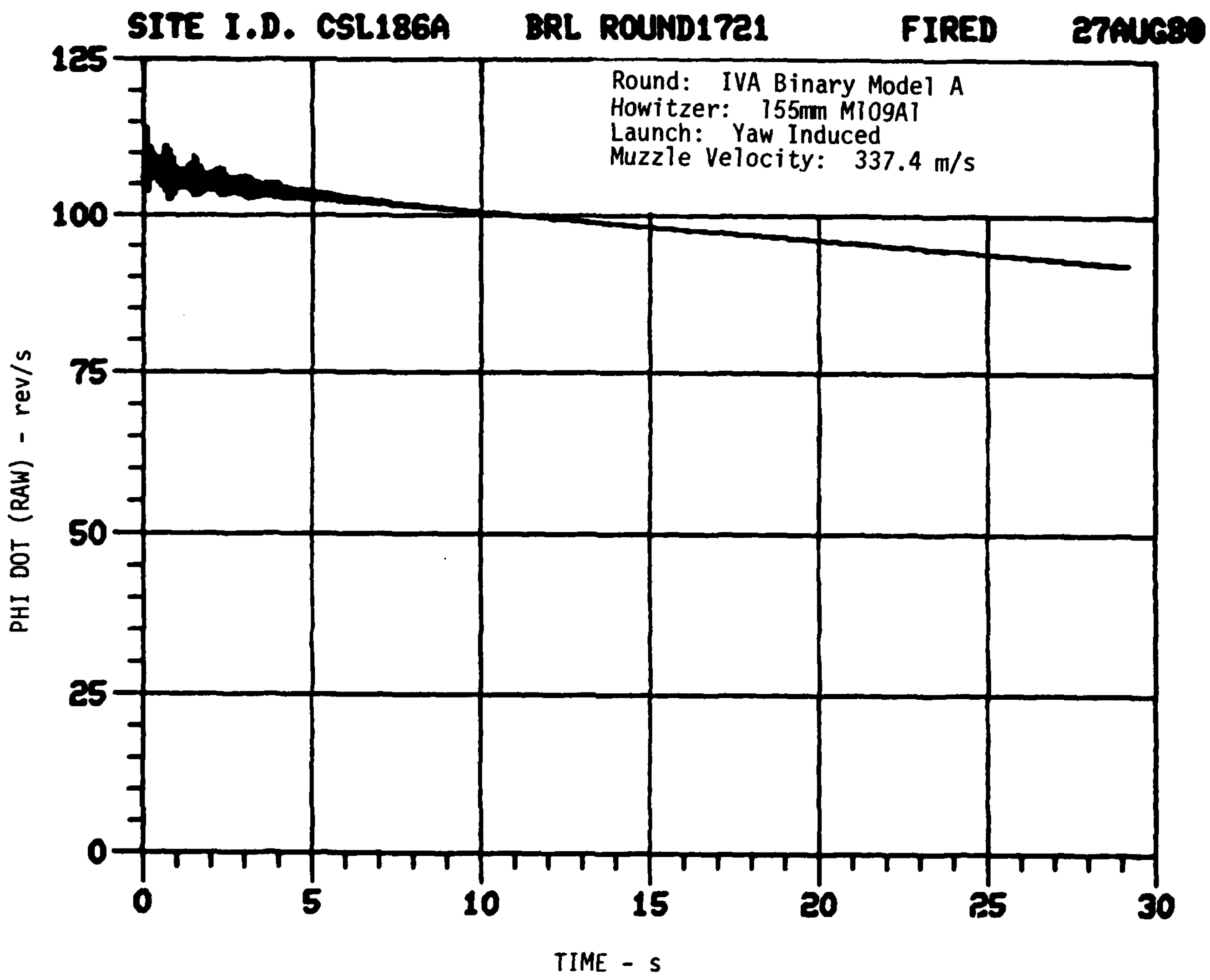

Figure 14. Phi Dot (Raw) versus Time (0-30 s) for Round 186A.

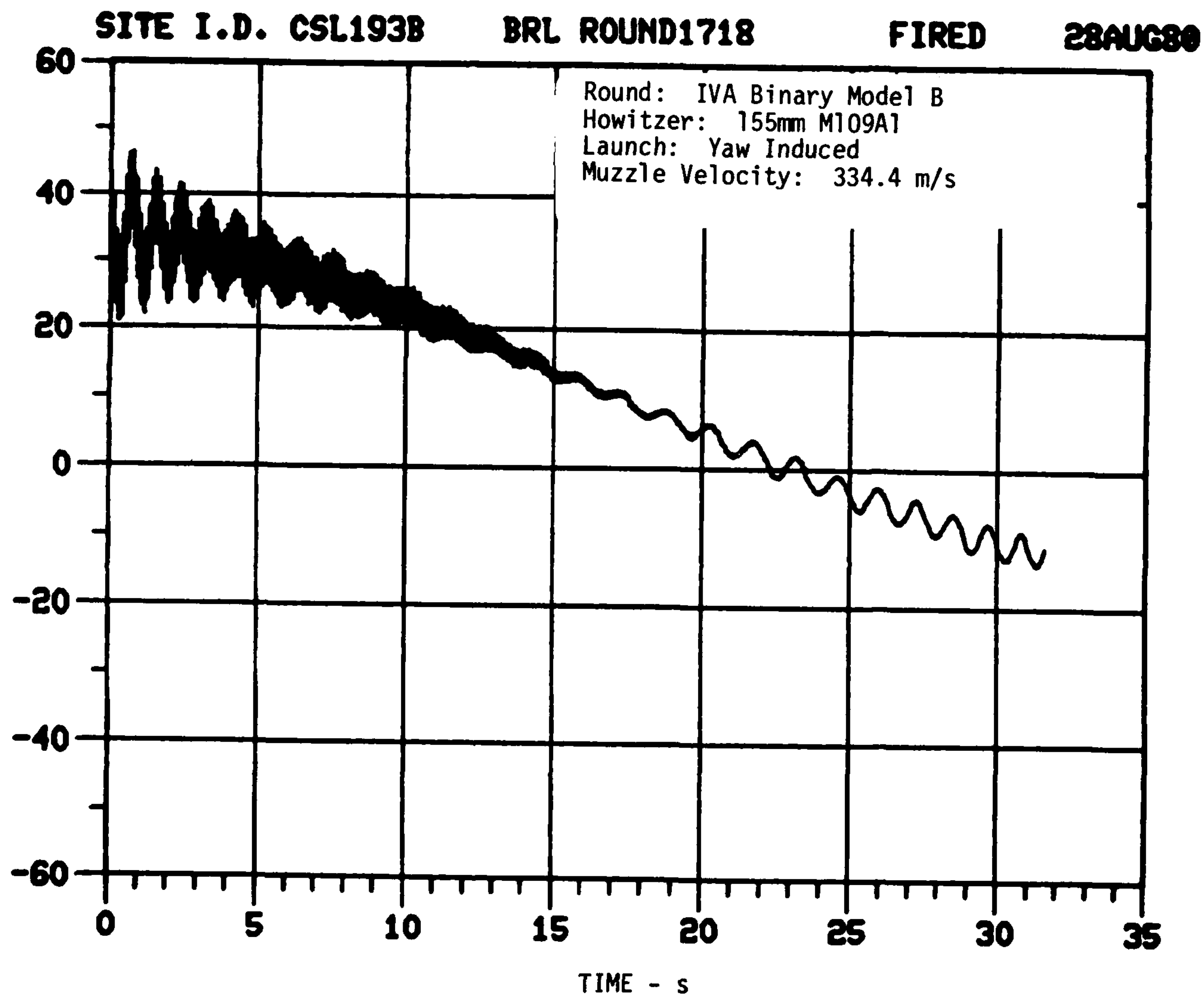

Figure 15. Sigma N versus Time (0-35 s) for Round 193B.

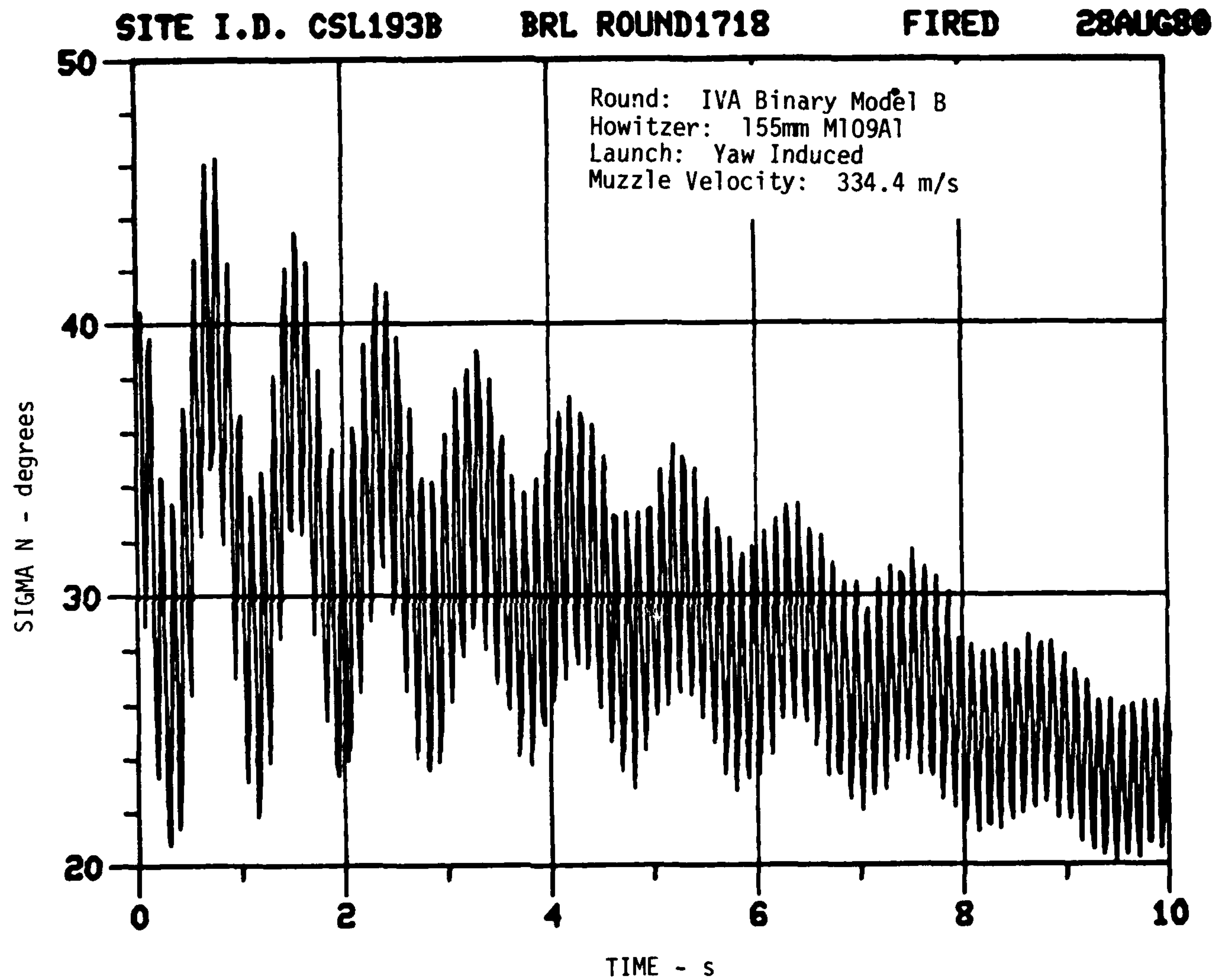

Figure 16. Sigma N versus Time (0-10 s) for Round 193B.

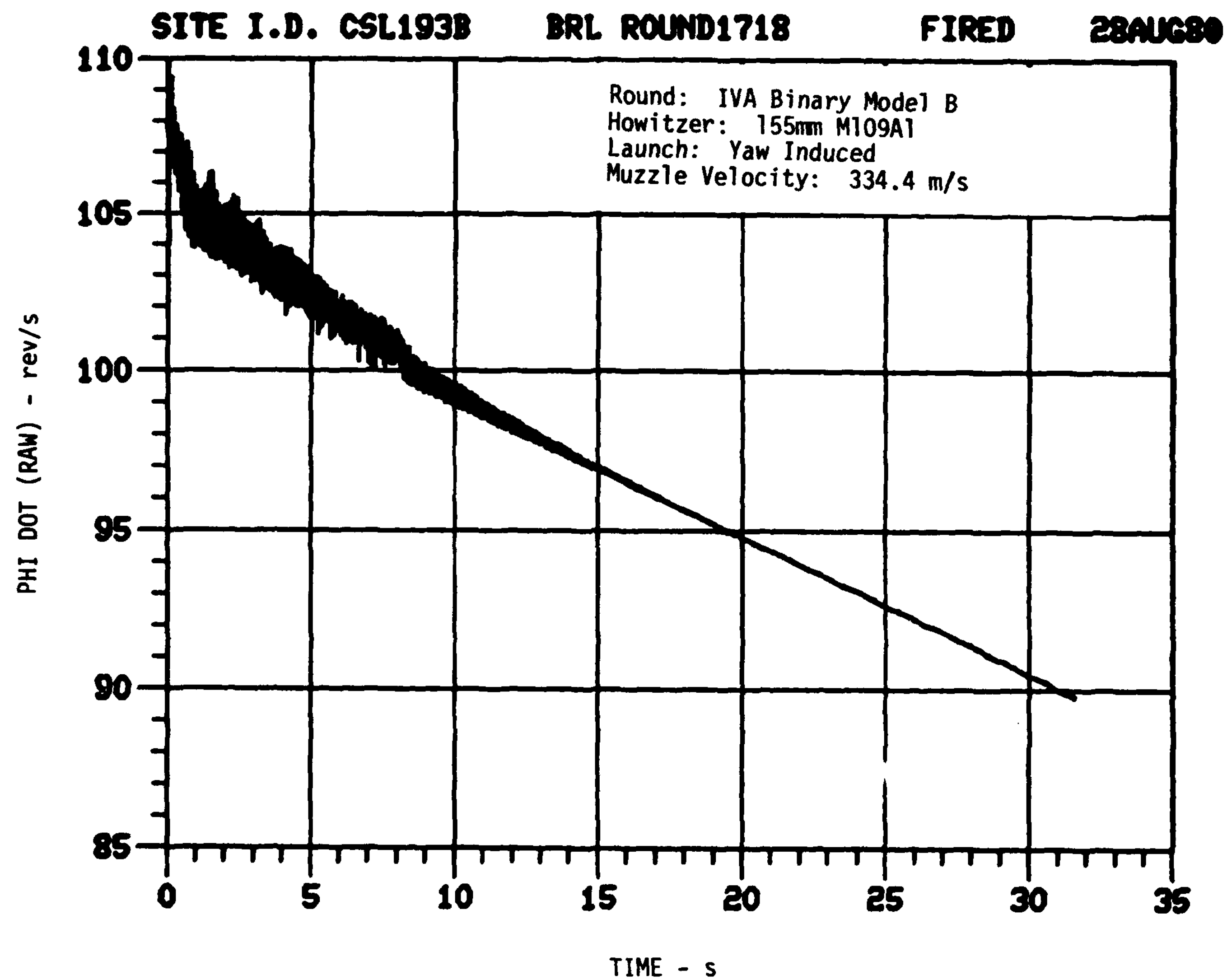

Figure 17. Phi Dot (Raw) versus Time (0-35 s) for Round 193B.

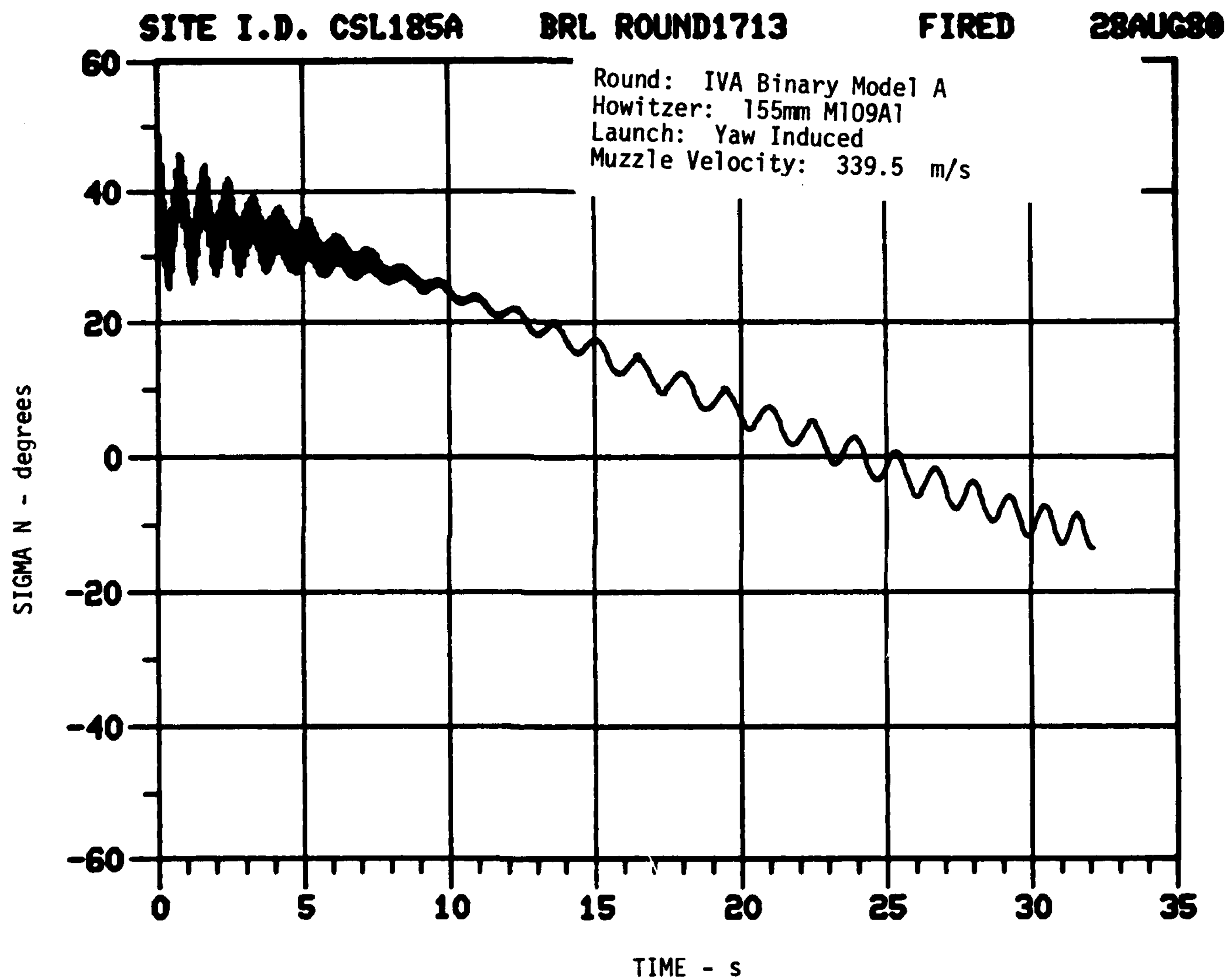

Figure 18. Sigma N versus Time (0-35 s) for Round 185A.

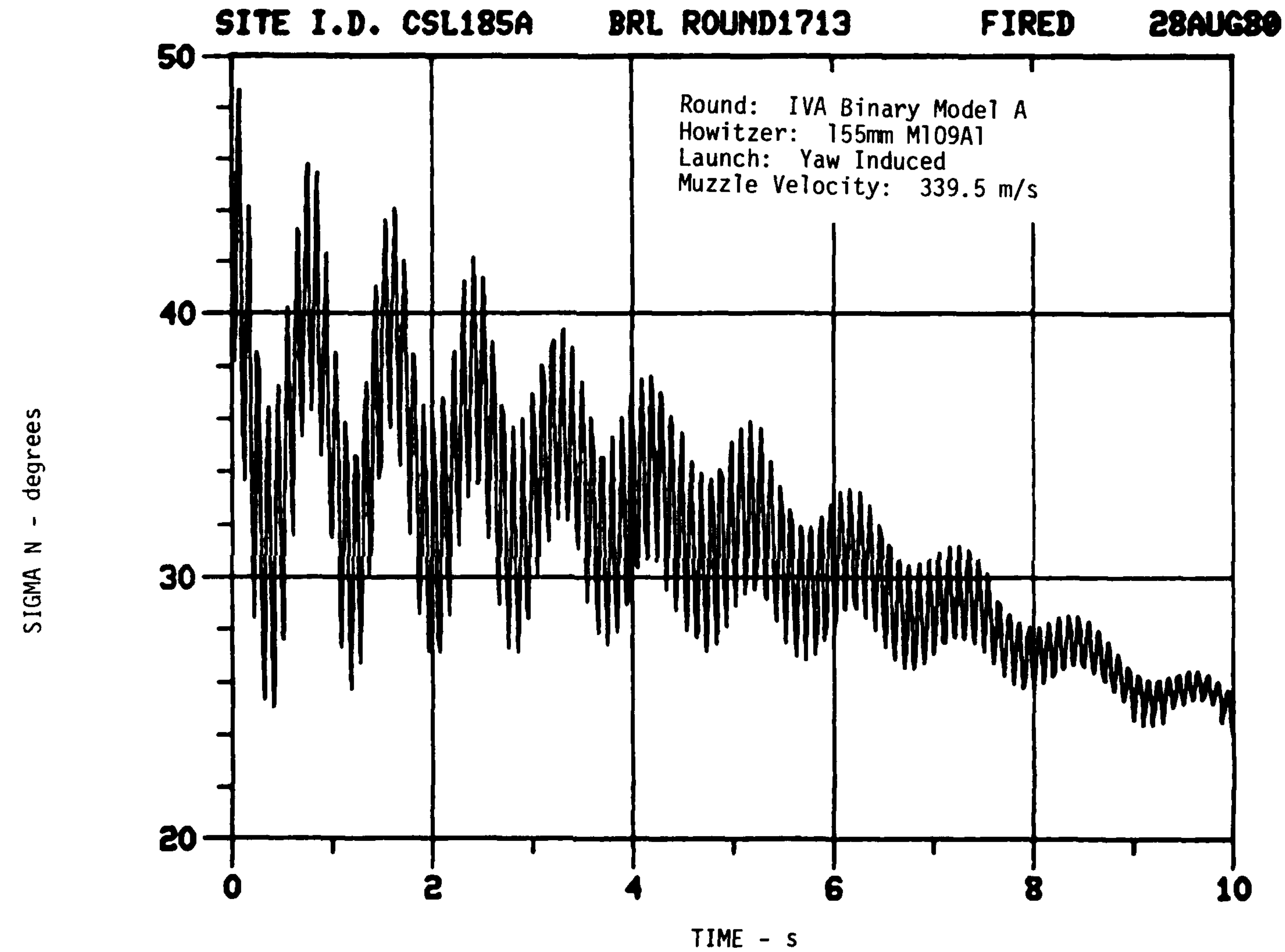

Figure 19. Sigma N versus Time (0-10 s) for Round 185A.

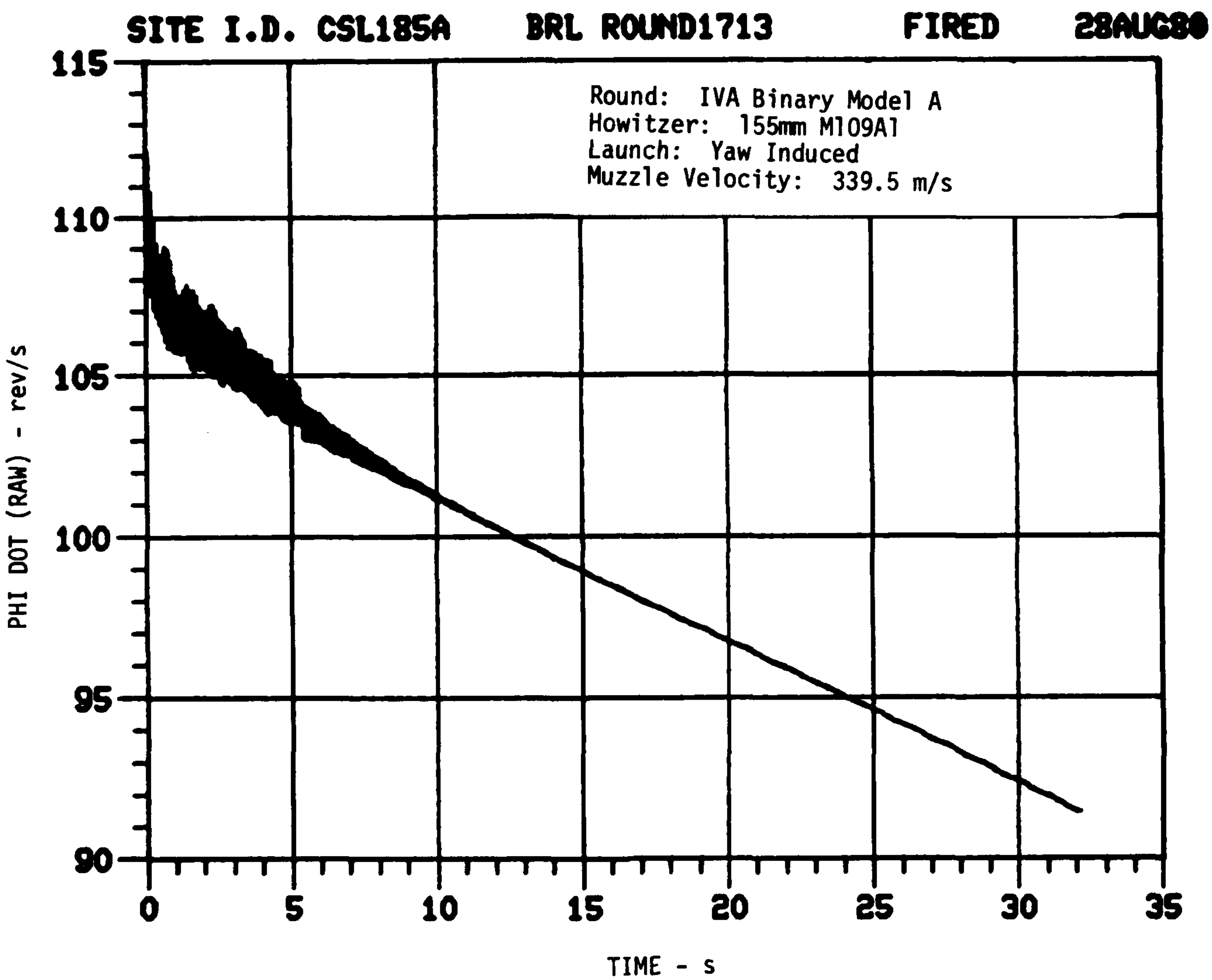

Figure 20. Phi Dot (Raw) versus Time (0-35 s) for Round 185A.

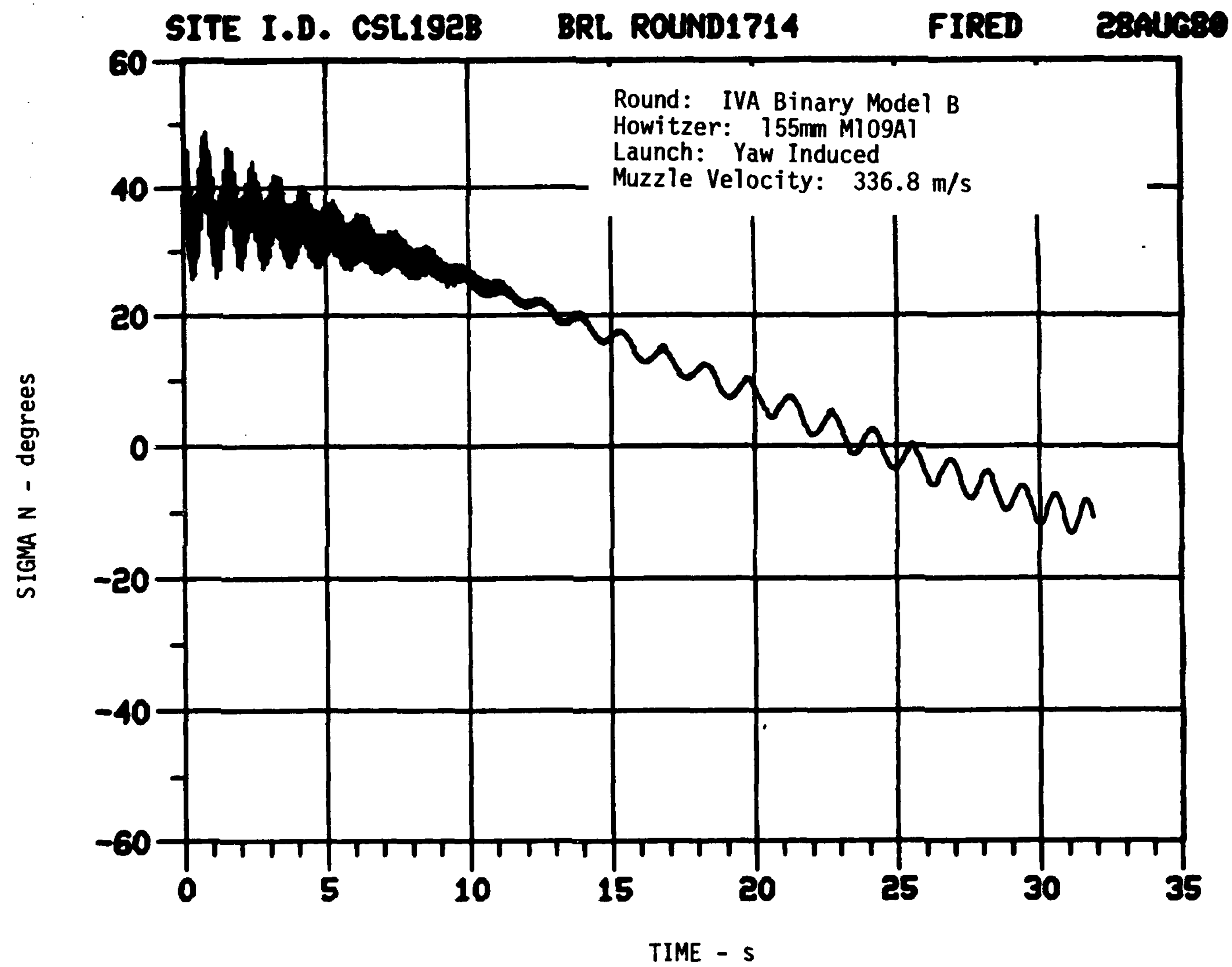

Figure 21. Sigma N versus Time (0-35 s) for Round 192B.

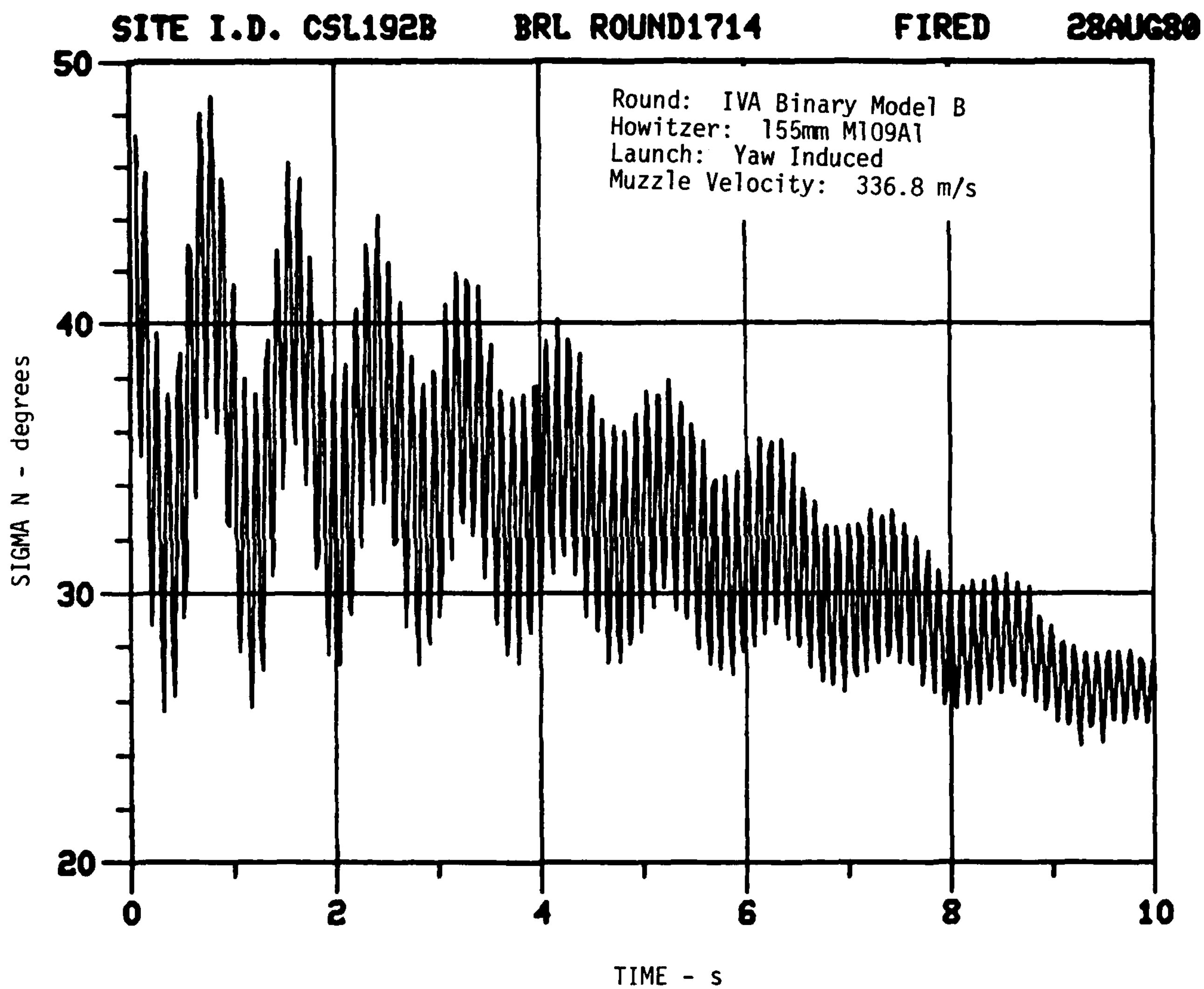

Figure 22. Sigma N versus Time (0-10 s) for Round 192B.

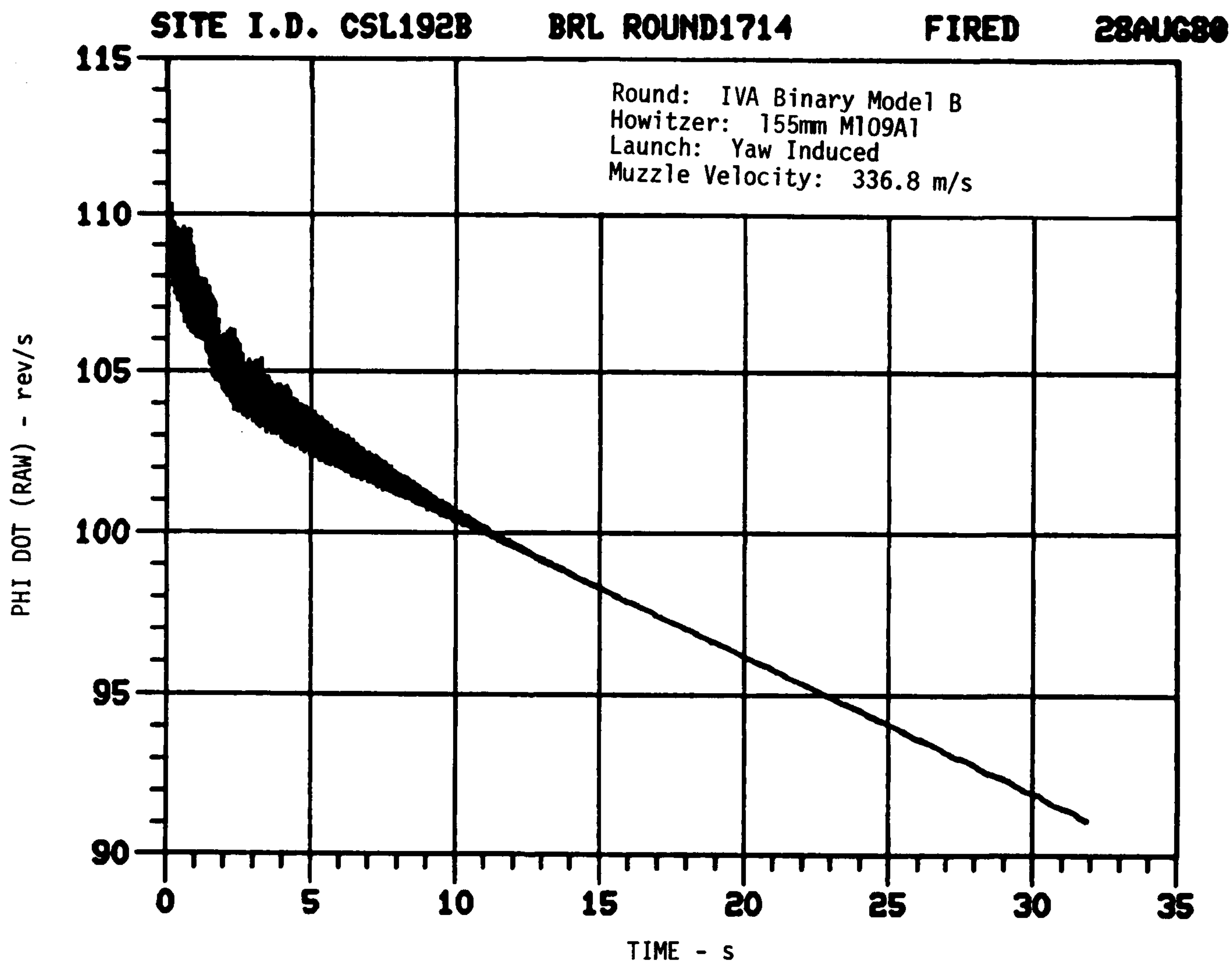

Figure 23. Phi Dot (Raw) versus Time (0-35 s) for Round 192B.

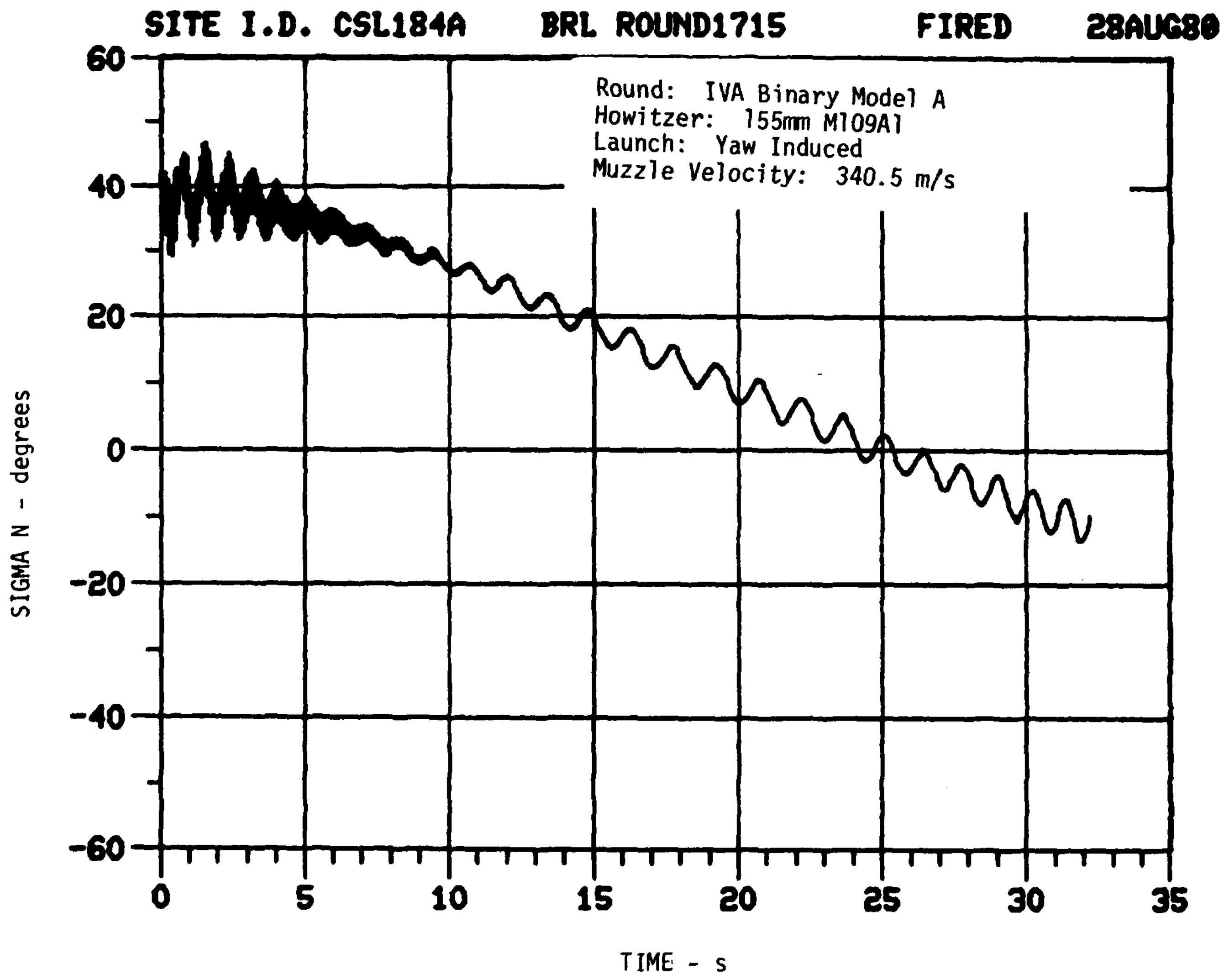

Figure 24. Sigma N versus Time (0-35 s) for Round 184A.

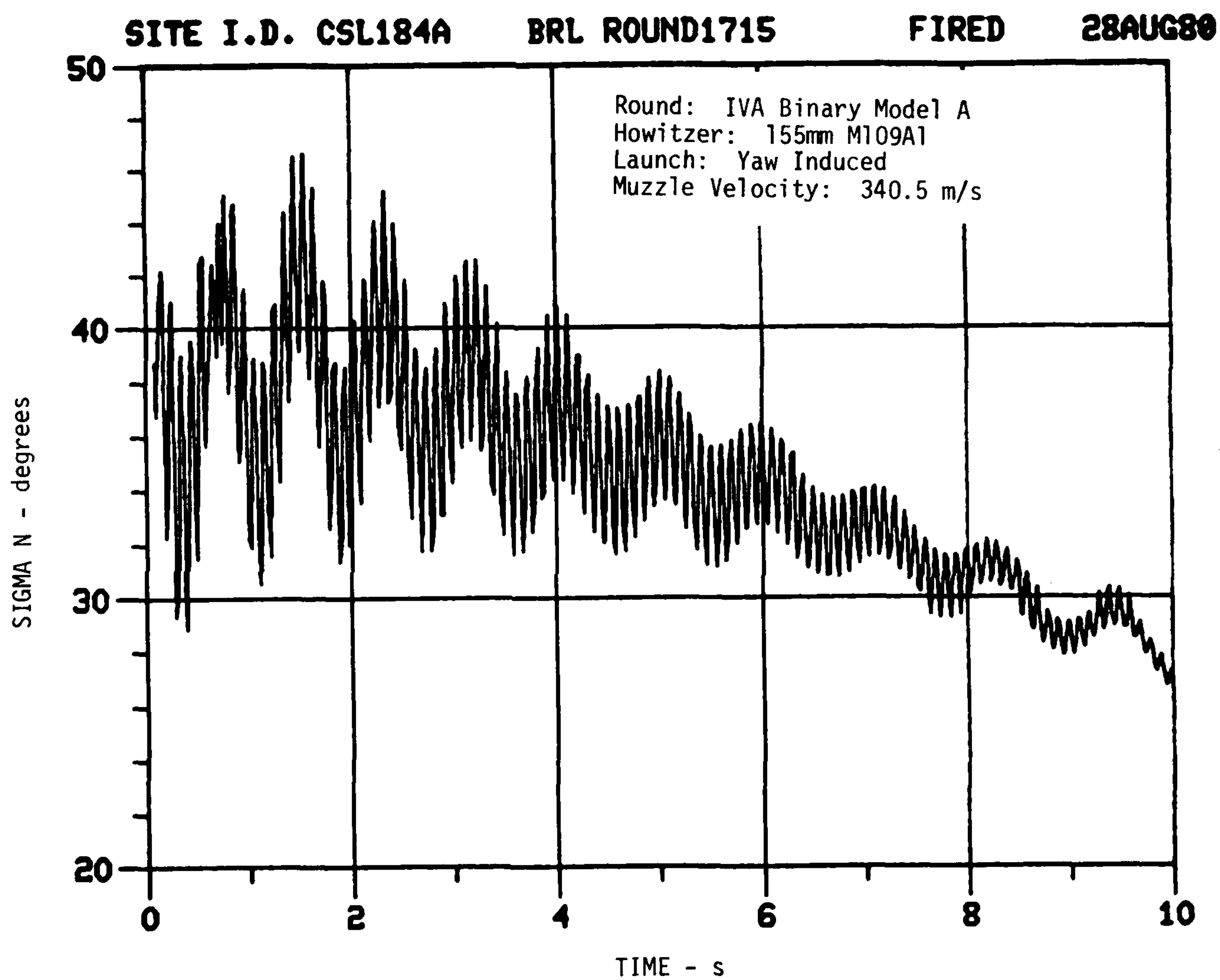

Figure 25. Sigma N versus Time (0-10 s) for Round 184A.

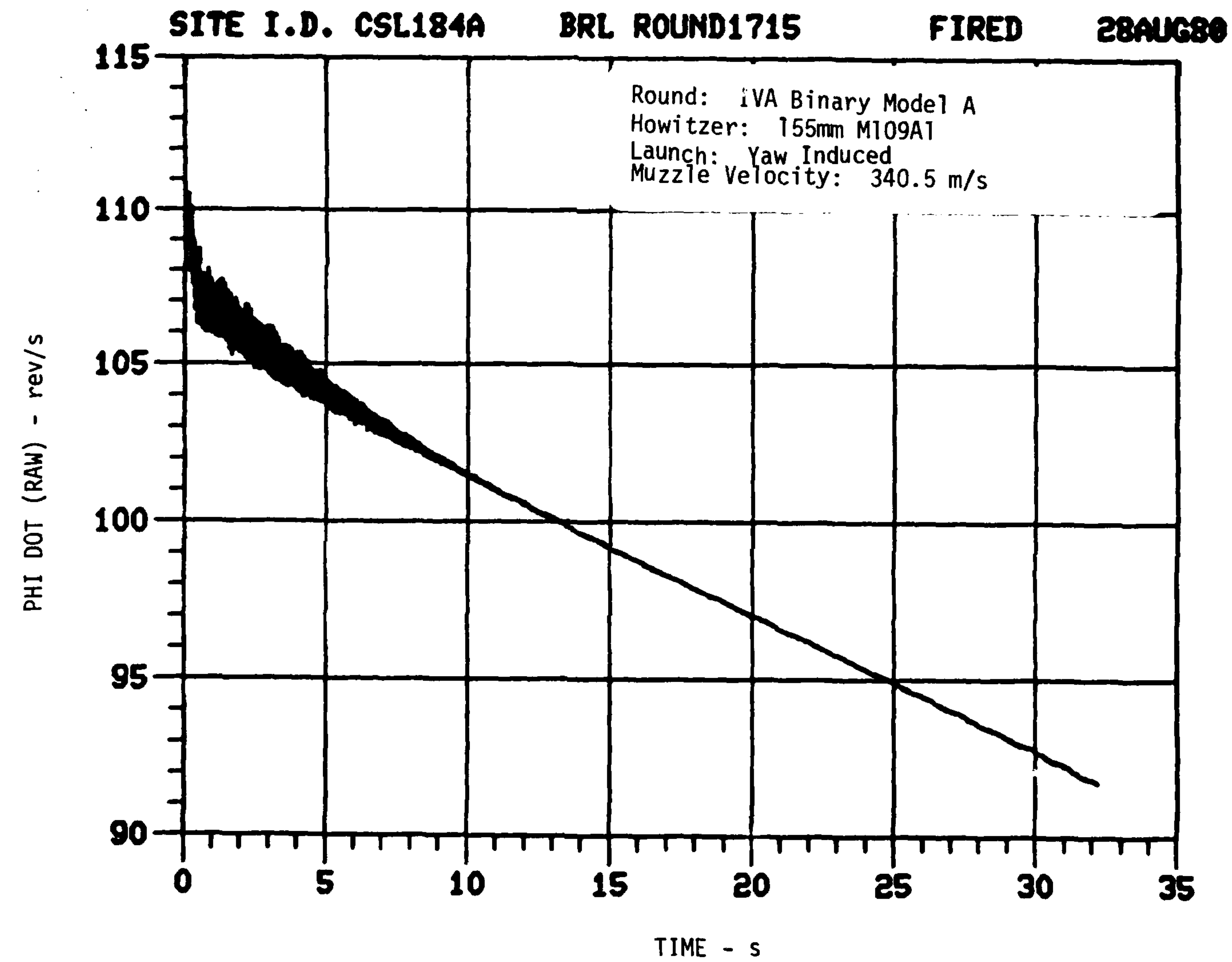

Figure 26. Phi Dot (Raw) versus Time (0-35 s) for Round 184A.

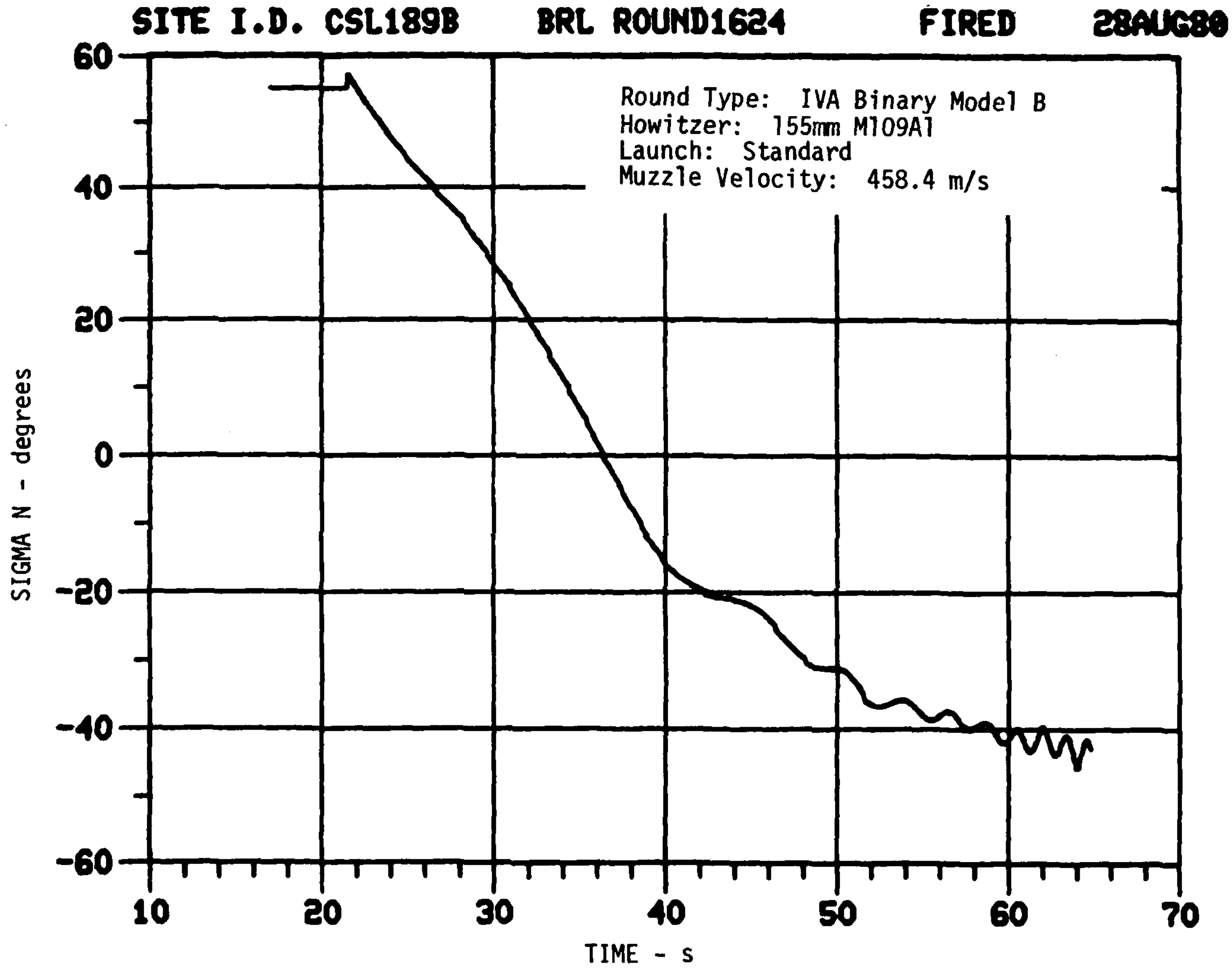

Figure 27. Sigma N versus Time (10-70 s) for Round 189B.

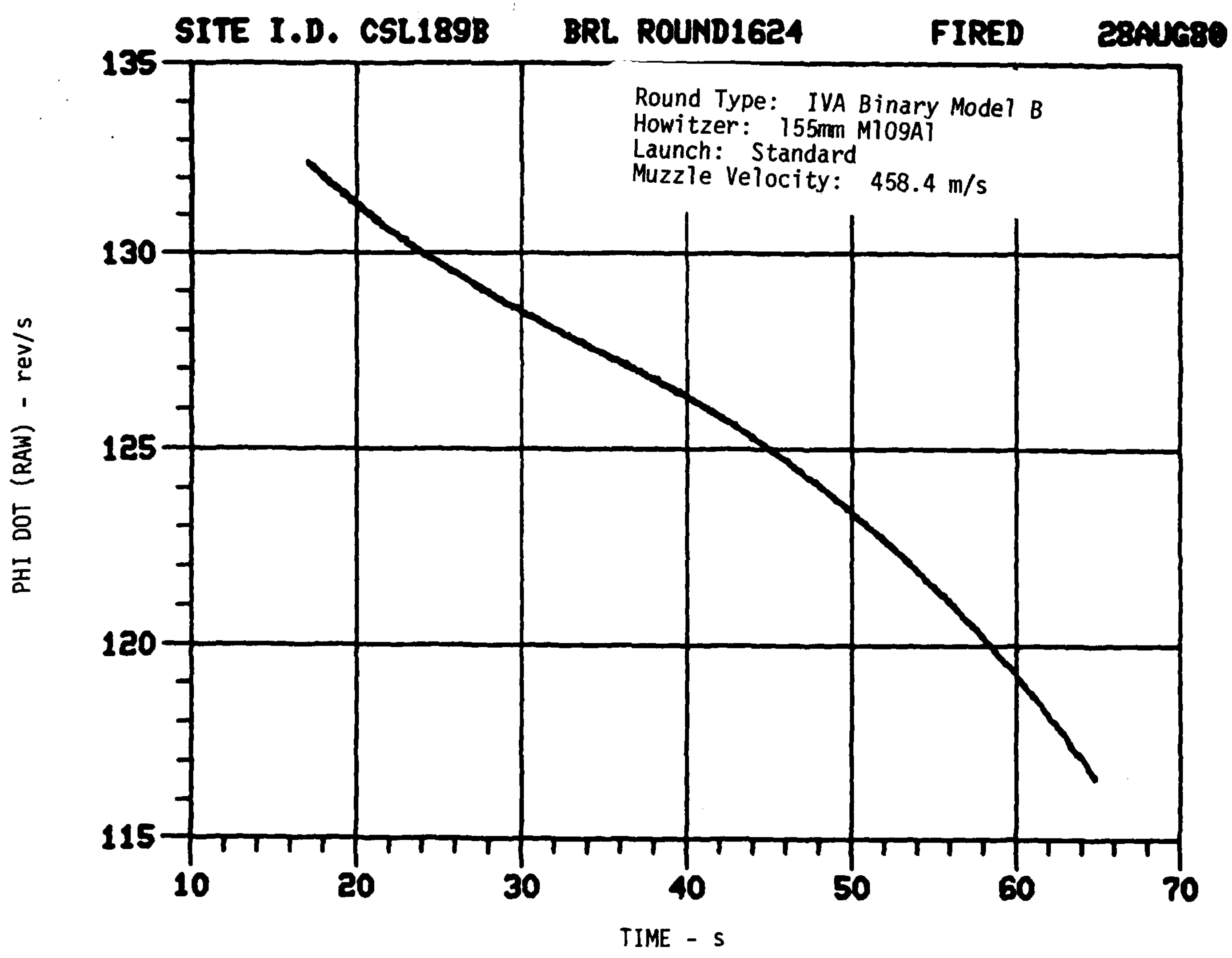

Figure 28. Phi Dot (Raw) versus Time (10-70 s) for Round 189B.

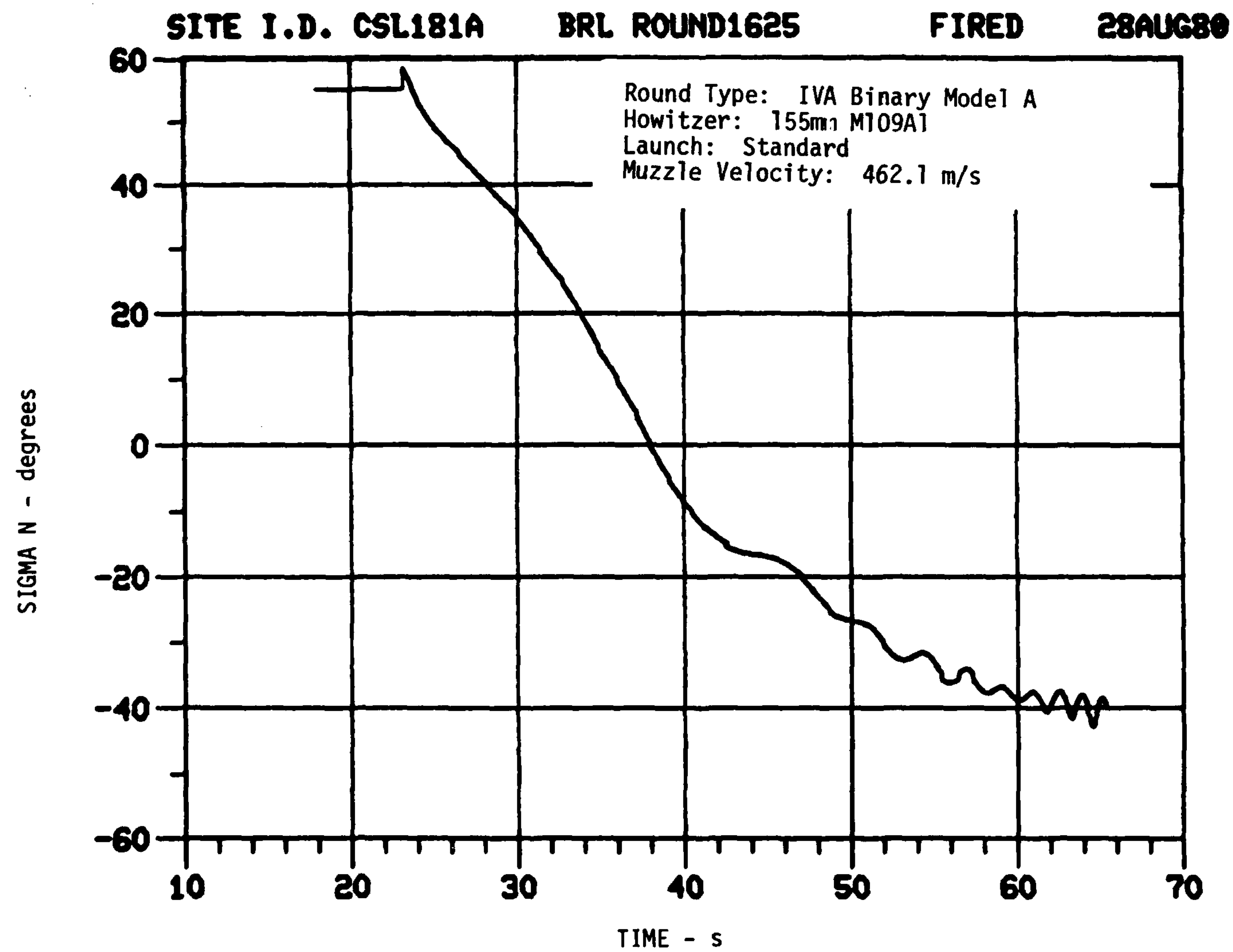

Figure 29. Sigma N versus Time (10-70 s) for Round 181A.

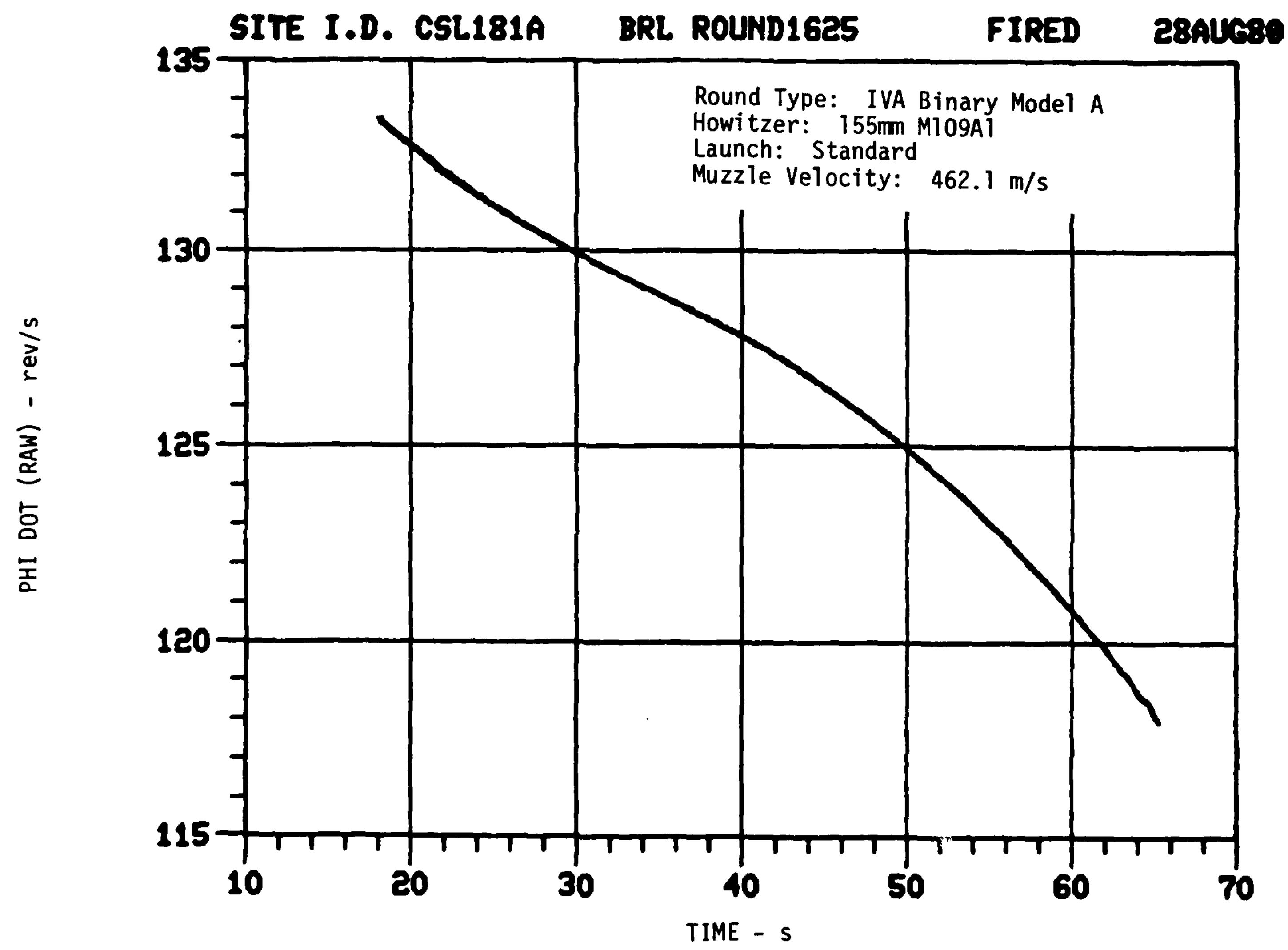

Figure 30. Phi Dot (Raw) versus Time (10-70 s) for Round 181A.

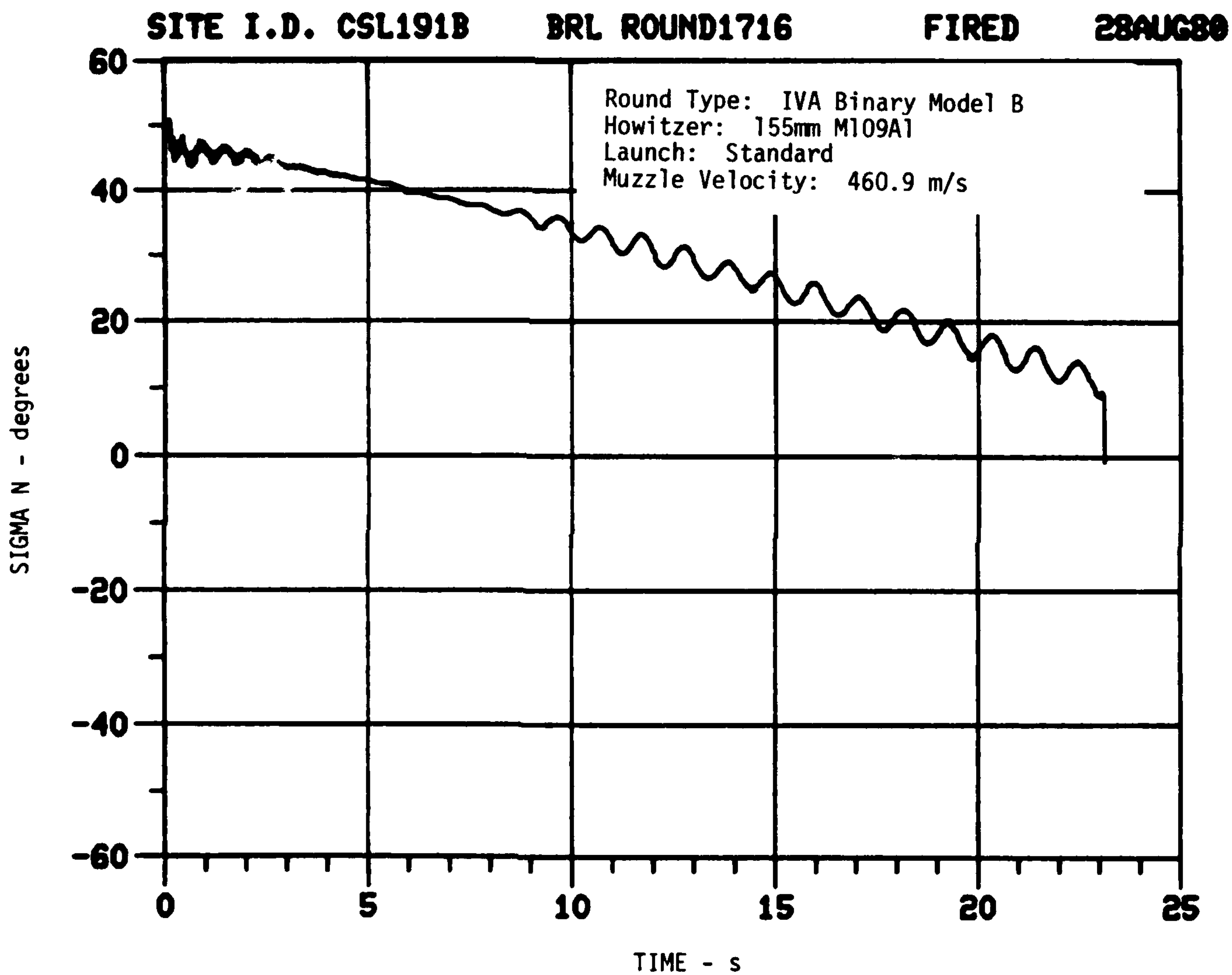

Figure 31. Sigma N versus Time (0-25 s) for Round 191B.

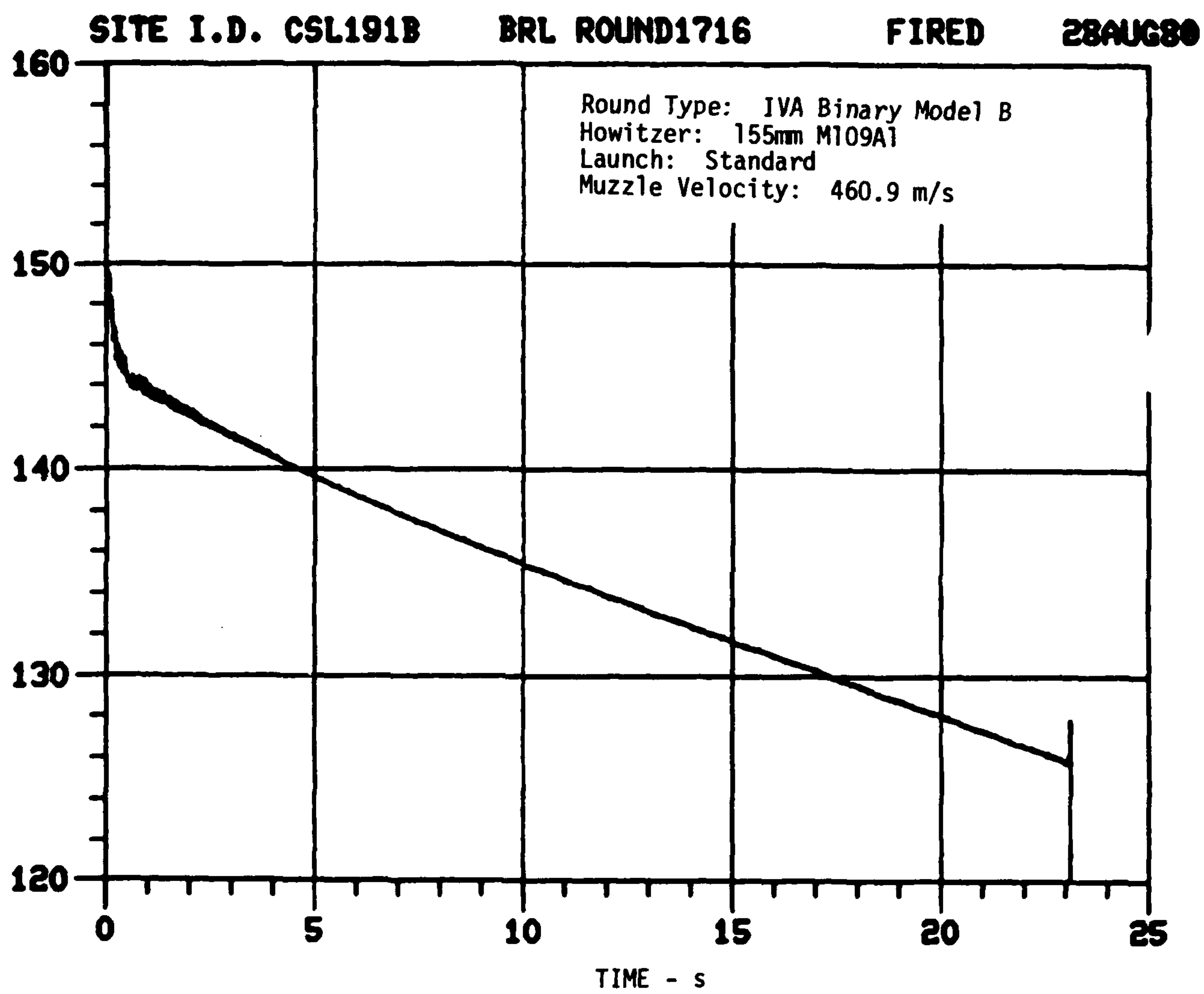

Figure 32. Phi Dot (Raw) versus Time (0-25 s) for Round 191B.

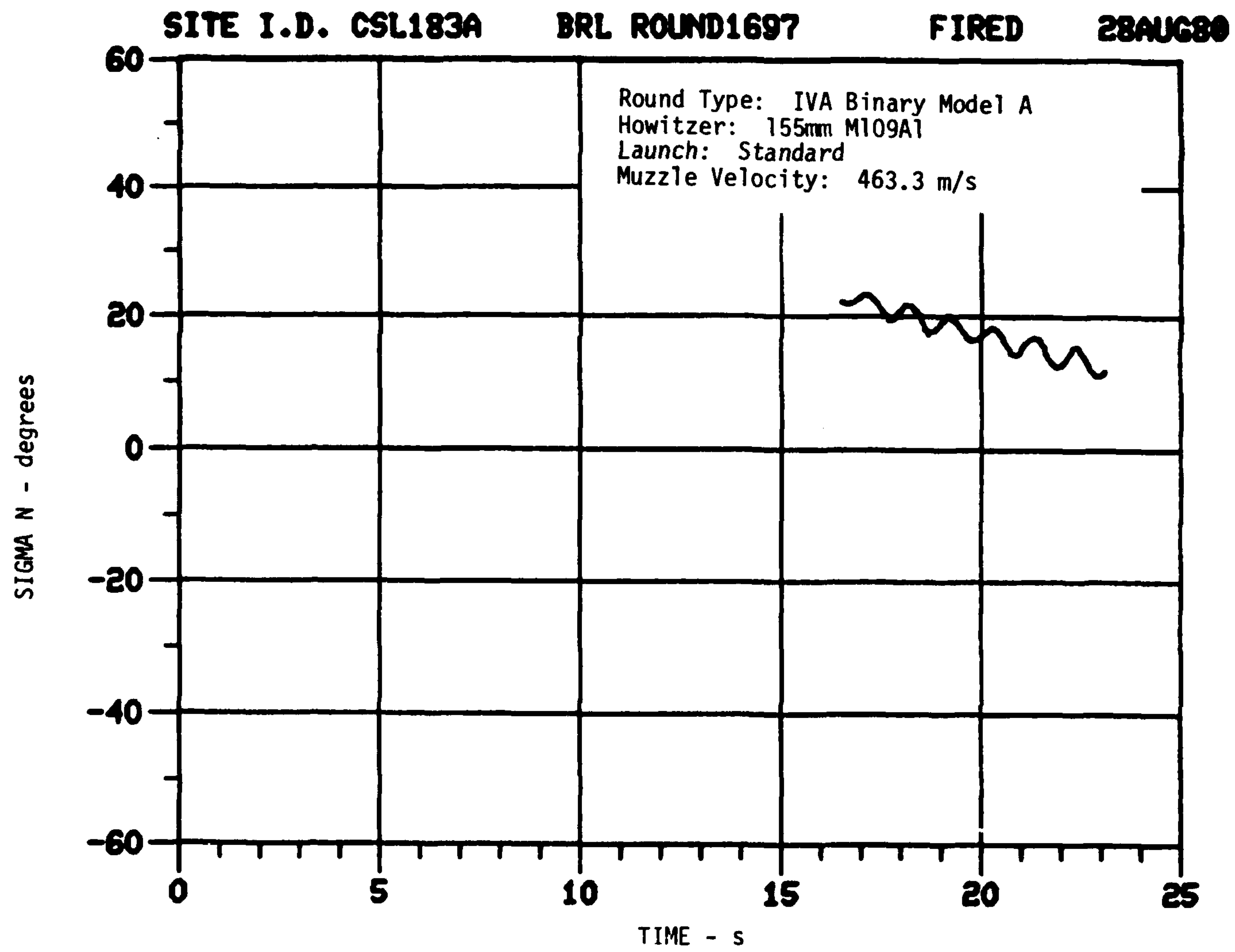

Figure 33. Sigma N versus Time (0-25 s) for Round 183A.

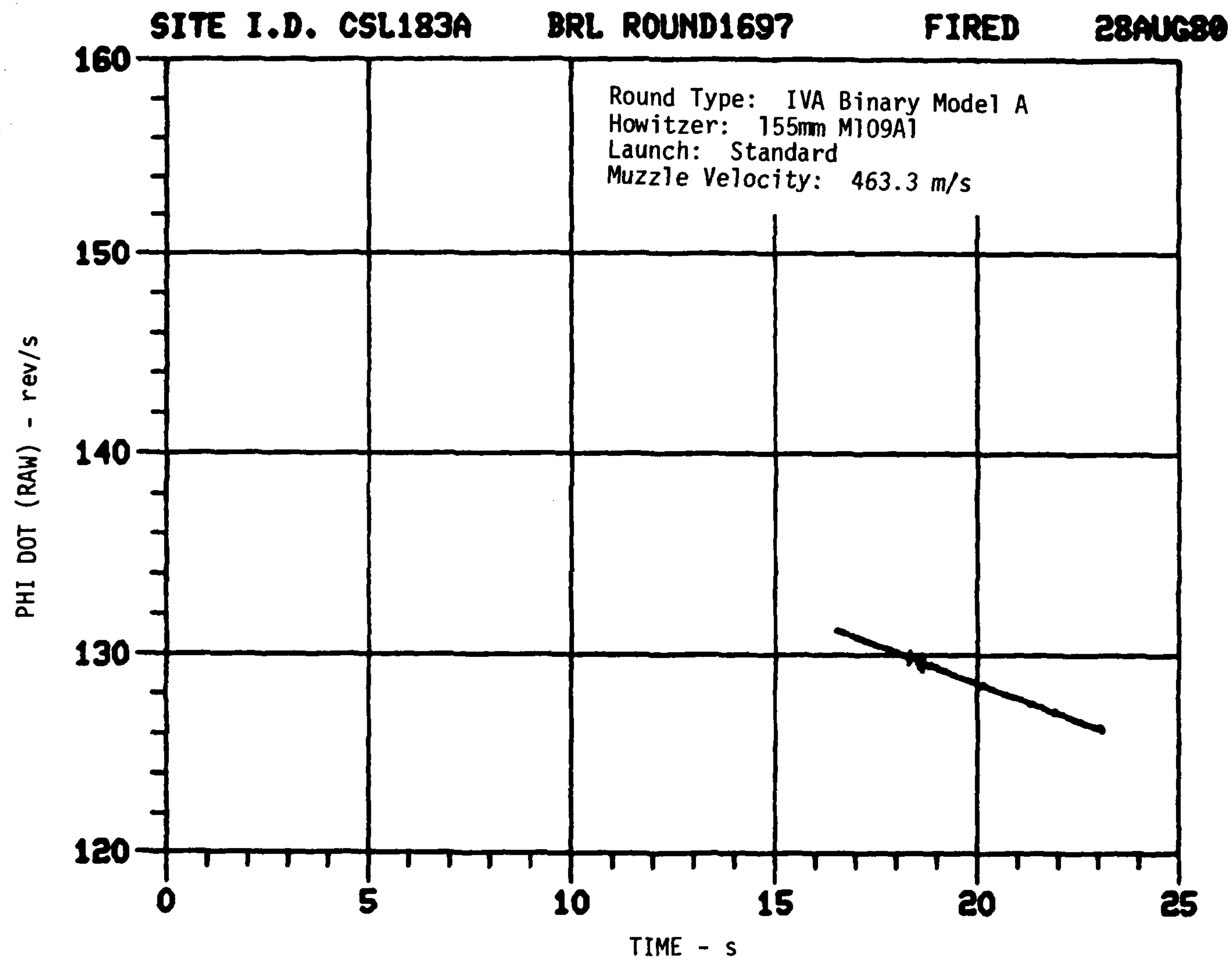

Figure 34. Phi Dot (Raw) versus Time (0-25 s) for Round 183A.

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